Method and Apparatus and Program Storage Device adapted for Automatic Drill Bit Selection Based on Earth Properties

CROSS REFERENCE TO RELATED APPLICATIONS

[001] This application is related to pending application serial number ____ filed _____, corresponding to attorney docket number 94.0076; and it is related to pending application serial number ____ filed _____, corresponding to attorney docket number 94.0077; and it is related to pending application serial number ____ filed _____, corresponding to attorney docket number 94.0078; and it is related to pending application serial number ____ filed _____, corresponding to attorney docket number 94.0080.

BACKGROUND OF THE INVENTION

[002] The subject matter of the present invention relates to a software system adapted to be stored in a computer system, such as a personal computer, for providing automatic drill bit selection based on Earth properties.

[003] Minimizing wellbore costs and associated risks requires wellbore construction planning techniques that account for the interdependencies involved in the wellbore design. The inherent difficulty is that most design processes and systems exist as independent tools used for individual tasks by the various disciplines involved in the planning process. In an environment where increasingly difficult wells of higher value are being drilled with fewer resources, there is now, more than ever, a need for a rapid well-planning, cost, and risk assessment tool.

[004] This specification discloses a software system representing an automated process adapted for integrating both a wellbore construction planning workflow and accounting

for process interdependencies. The automated process is based on a drilling simulator, the process representing a highly interactive process which is encompassed in a software system that: (1) allows well construction practices to be tightly linked to geological and geomechanical models, (2) enables asset teams to plan realistic well trajectories by automatically generating cost estimates with a risk assessment, thereby allowing quick screening and economic evaluation of prospects, (3) enables asset teams to quantify the value of additional information by providing insight into the business impact of project uncertainties, (4) reduces the time required for drilling engineers to assess risks and create probabilistic time and cost estimates faithful to an engineered well design, (5) permits drilling engineers to immediately assess the business impact and associated risks of applying new technologies, new procedures, or different approaches to a well design. Discussion of these points illustrate the application of the workflow and verify the value, speed, and accuracy of this integrated well planning and decision-support tool.

[005] The selection of Drill bits is a manual subjective process based heavily on personal, previous experiences. The experience of the individual recommending or selecting the drill bits can have a large impact on the drilling performance for the better or for the worse. The fact that bit selection is done primarily based on personal experiences and uses little information of the actual rock to be drilled makes it very easy to choose the incorrect bit for the application.

SUMMARY OF THE INVENTION

[006] One aspect of the present invention involves a method of generating and recording or displaying a sequence of drill bits, chosen from among a plurality of bit candidates to be used, for drilling an Earth formation in response to input data representing Earth formation characteristics of the formation to be drilled, comprising the steps of: comparing the input data representing the characteristics of the formation to be drilled with a set of historical data including a plurality of sets of Earth formation characteristics and a corresponding plurality of sequences of drill bits to be used in connection with the sets of Earth formation characteristics, and locating a substantial match between the characteristics of the formation to be drilled associated with the input data and at least one of the plurality of sets of Earth formation characteristics associated with the set of historical data; when the substantial match is found, generating one of the plurality of sequences of drill bits in response thereto; and recording or displaying the one of the plurality of sequences of drill bits on a recorder or display device.

[007] Another aspect of the present invention involves a program storage device readable by a machine tangibly embodying a program of instructions executable by the machine to perform method steps for generating and recording or displaying a sequence of drill bits, chosen from among a plurality of bit candidates, for drilling an Earth formation in response to input data representing Earth formation characteristics of the formation to be drilled, the method steps comprising: comparing the input data representing the characteristics of the formation to be drilled with a set of historical data including a plurality of sets of Earth formation characteristics and a corresponding plurality of sequences of drill bits to be used in connection with the sets of Earth formation characteristics, and locating a substantial match between the characteristics of the formation to be drilled associated with the input data and at least one of the plurality of sets of Earth formation characteristics associated with the set of historical data; when the substantial match is found, generating one of the plurality of sequences of drill bits in

response thereto; and recording or displaying the one of the plurality of sequences of drill bits on a recorder or display device.

[008] Another aspect of the present invention involves a method of selecting one or more drill bits to drill in an Earth formation, comprising the steps of: (a) reading variables and constants, (b) reading catalogs, (c) building a cumulative rock strength curve from casing point to casing point, (d) determining a required hole size, (e) finding the bit candidates that match the closest unconfined compressive strength of a rock to drill, (f) determining an end depth of a bit by comparing a historical drilling energy with a cumulative rock strength curve for all bit candidates, (g) calculating a cost per foot for each bit candidate taking into account the rig rate, trip speed and drilling rate of penetration, (h) evaluating which bit candidate is most economic, (i) calculating a remaining cumulative rock strength to casing point, and (j) repeating steps (e) to (i) until an end of the hole section is reached.

[009] Another aspect of the present invention involves a program storage device readable by a machine tangibly embodying a program of instructions executable by the machine to perform method steps for selecting one or more drill bits to drill in an Earth formation, the method steps comprising: (a) reading variables and constants, (b) reading catalogs, (c) building a cumulative rock strength curve from casing point to casing point, (d) determining a required hole size, (e) finding the bit candidates that match the closest unconfined compressive strength of a rock to drill, (f) determining an end depth of a bit by comparing a historical drilling energy with a cumulative rock strength curve for all bit candidates, (g) calculating a cost per foot for each bit candidate taking into account the rig rate, trip speed and drilling rate of penetration, (h) evaluating which bit candidate is most economic, (i) calculating a remaining cumulative rock strength to casing point, and (j) repeating steps (e) to (i) until an end of the hole section is reached.

[0010] Another aspect of the present invention involves a method of selecting a bit to drill an Earth formation, comprising the steps of: (a) receiving a list of bit candidates and

determining an average rock strength for each bit candidate; (b) determining a resultant cumulative rock strength for the each bit candidate in response to the average rock strength for the each bit candidate; (c) performing an economic analysis in connection with the each bit candidate to determine if the each bit candidate is an inexpensive bit candidate; and (d) selecting the each bit candidate to be the bit to drill the Earth formation when the resultant cumulative rock strength is greater than or equal to a predetermined value and the each bit candidate is an inexpensive bit candidate.

[0011] Another aspect of the present invention involves a program storage device readable by a machine tangibly embodying a program of instructions executable by the machine to perform method steps for selecting a bit to drill an Earth formation, the method steps comprising: (a) receiving a list of bit candidates and determining an average rock strength for each bit candidate; (b) determining a resultant cumulative rock strength for the each bit candidate in response to the average rock strength for the each bit candidate; (c) performing an economic analysis in connection with the each bit candidate to determine if the each bit candidate is an inexpensive bit candidate; and (d) selecting the each bit candidate to be the bit to drill the Earth formation when the resultant cumulative rock strength is greater than or equal to a predetermined value and the each bit candidate is an inexpensive bit candidate.

[0012] Another aspect of the present invention involves a system adapted for selecting a bit to drill an Earth formation, comprising: apparatus adapted for receiving a list of bit candidates and determining an average rock strength for each bit candidate; apparatus adapted for determining a resultant cumulative rock strength for the each bit candidate in response to the average rock strength for the each bit candidate; apparatus adapted for performing an economic analysis in connection with the each bit candidate to determine if the each bit candidate is an inexpensive bit candidate; and apparatus adapted for selecting the each bit candidate to be the bit to drill the Earth formation when the resultant cumulative rock strength is greater than or equal to a predetermined value and the each bit candidate is an inexpensive bit candidate.

[0013] Further scope of applicability of the present invention will become apparent from the detailed description presented hereinafter. It should be understood, however, that the detailed description and the specific examples, while representing a preferred embodiment of the present invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become obvious to one skilled in the art from a reading of the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] A full understanding of the present invention will be obtained from the detailed description of the preferred embodiment presented hereinbelow, and the accompanying drawings, which are given by way of illustration only and are not intended to be limitative of the present invention, and wherein:

[0015] figure 1 illustrates a software architecture schematic indicating a modular nature to support custom workflows;

[0016] figure 2 including figures 2A, 2B, 2C, and 2D illustrates a typical task view consisting of workflow, help and data canvases;

[0017] figure 3 including figures 3A, 3B, 3C, and 3D illustrates wellbore stability, mud weights, and casing points;

[0018] figure 4 including figures 4A, 4B, 4C, and 4D illustrates risk assessment;

[0019] figure 5 including figures 5A, 5B, 5C, and 5D illustrates a Monte Carlo time and cost distribution;

[0020] figure 6 including figures 6A, 6B, 6C, and 6D illustrates a probabilistic time and cost vs. depth;

[0021] figure 7 including figures 7A, 7B, 7C, and 7D illustrates a summary montage;

[0022] figure 8 illustrates a workflow in an 'Automatic Well Planning Software System';

[0023] figure 9A illustrates a computer system which stores an Automatic Well Planning Risk Assessment Software;

[0024] figure 9B illustrates a display as shown on a Recorder or Display device of the Computer System of figure 9A;

[0025] figure 10 illustrates a detailed construction of the Automatic Well Planning Risk Assessment Software stored in the Computer System of figure 9A;

[0026] figure 11 illustrates a block diagram representing a construction of the Automatic Well Planning Risk Assessment software of figure 10 which is stored in the Computer System of figure 9A;

[0027] figure 12 illustrates a Computer System which stores an Automatic Well Planning Bit Selection software in accordance with the present invention;

[0028] figure 13 illustrates a detailed construction of the Automatic Well Planning Bit Selection Software stored in the Computer System of figure 12 in accordance with the present invention;

[0029] figure 14A illustrates a block diagram representing a functional operation of the Automatic Well Planning Bit Selection software of figure 13 of the present invention;

[0030] figure 14B illustrates another block diagram representing a functional operation of the Automatic Well Planning Bit Selection software of figure 13 of the present invention;

[0031] figure 15 including figures 15A, 15B, 15C, and 15D illustrates a Bit Selection display which is generated by a Recorder or Display device associated with the Computer System of figure 12 which stores the Automatic Well Planning Bit Selection software in accordance with the present invention; and

[0032] figures 16 is used in a functional specification disclosed in this specification.

DETAILED DESCRIPTION

[0033] An 'Automatic Well Planning Software System' is disclosed in this specification. The 'Automatic Well Planning Software System' of the present invention is a "smart" tool for rapid creation of a detailed drilling operational plan that provides economics and risk analysis. The user inputs trajectory and earth properties parameters; the system uses this data and various catalogs to calculate and deliver an optimum well design thereby generating a plurality of outputs, such as drill string design, casing seats, mud weights, bit selection and use, hydraulics, and the other essential factors for the drilling task. System tasks are arranged in a single workflow in which the output of one task is included as input to the next. The user can modify most outputs, which permits fine-tuning of the input values for the next task. The 'Automatic Well Planning Software System' has two primary user groups: (1) Geoscientist: Works with trajectory and earth properties data; the 'Automatic Well Planning Software System' provides the necessary drilling engineering calculations; this allows the user to scope drilling candidates rapidly in terms of time, costs, and risks; and (2) Drilling engineer: Works with wellbore geometry and drilling parameter outputs to achieve optimum activity plan and risk assessment; Geoscientists typically provide the trajectory and earth properties data. The scenario, which consists of the entire process and its output, can be exported for sharing with other users for peer review or as a communication tool to facilitate project management between office and field. Variations on a scenario can be created for use in business decisions. The 'Automatic Well Planning Software System' can also be used as a training tool for geoscientists and drilling engineers.

[0034] The 'Automatic Well Planning Software System' will enable the entire well construction workflow to be run through quickly. In addition, the 'Automatic Well Planning Software System' can ultimately be updated and re-run in a time-frame that supports operational decision making. The entire replanning process must be fast enough to allow users to rapidly iterate to refine well plans through a series of what-if scenarios.

[0035] The decision support algorithms provided by the 'Automatic Well Planning Software System' disclosed in this specification would link geological and geomechanical data with the drilling process (casing points, casing design, cement, mud, bits, hydraulics, etc) to produce estimates and a breakdown of the well time, costs, and risks. This will allow interpretation variations, changes, and updates of the Earth Model to be quickly propogated through the well planning process.

[0036] The software associated with the aforementioned 'Automatic Well Planning Software System' accelerates the prospect selection, screening, ranking, and well construction workflows. The target audiences are two fold: those who generate drilling prospects, and those who plan and drill those prospects. More specifically, the target audiences include: Asset Managers, Asset Teams (Geologists, Geophysicists, Reservoir Engineers, and Production Engineers), Drilling Managers, and Drilling Engineers.

[0037] Asset Teams will use the software associated with the 'Automatic Well Planning Software System' as a scoping tool for cost estimates, and assessing mechanical feasibility, so that target selection and well placement decisions can be made more knowledgeably, and more efficiently. This process will encourage improved subsurface evaluation and provide a better appreciation of risk and target accessibility. Since the system can be configured to adhere to company or local design standards, guidelines, and operational practices, users will be confident that well plans are technically sound.

[0038] Drilling Engineers will use the software associated with the 'Automatic Well Planning Software System' disclosed in this specification for rapid scenario planning, risk identification, and well plan optimization. It will also be used for training, in planning centers, universities, and for looking at the drilling of specific wells, electronically drilling the well, scenario modeling and 'what-if' exercises, prediction and diagnosis of events, post-drilling review and knowledge transfer.

[0039] The software associated with the 'Automatic Well Planning Software System' will enable specialists and vendors to demonstrate differentiation amongst new or competing technologies. It will allow operators to quantify the risk and business impact of the application of these new technologies or procedures.

[0040] Therefore, the 'Automatic Well Planning Software System' disclosed in this specification will: (1) dramatically improve the efficiency of the well planning and drilling processes by incorporating all available data and well engineering processes in a single predictive well construction model, (2) integrate predictive models and analytical solutions for wellbore stability, mud weights & casing seat selection, tubular & hole size selection, tubular design, cementing, drilling fluids, bit selection, rate of penetration, BHA design, drillstring design, hydraulics, risk identification, operations planning, and probabilistic time and cost estimation, all within the framework of a mechanical earth model, (3) easily and interactively manipulate variables and intermediate results within individual scenarios to produce sensitivity analyses. As a result, when the 'Automatic Well Planning Software System' is utilized, the following results will be achieved: (1) more accurate results, (2) more effective use of engineering resources, (3) increased awareness, (4) reduced risks while drilling, (5) decreased well costs, and (6) a standard methodology or process for optimization through iteration in planning and execution. As a result, during the implementation of the 'Automatic Well Planning Software System' of the present invention, the emphasis was placed on architecture and usability.

[0041] In connection with the implementation of the 'Automatic Well Planning Software System', the software development effort was driven by the requirements of a flexible architecture which must permit the integration of existing algorithms and technologies with commercial-off-the-shelf (COTS) tools for data visualization. Additionally, the workflow demanded that the product be portable, lightweight and fast, and require a very small learning curve for users. Another key requirement was the ability to customize the workflow and configuration based on proposed usage, user profile and equipment availability.

[0042] The software associated with the 'Automatic Well Planning Software System' was developed using the 'Ocean' framework owned by Schlumberger Technology Corporation of Houston, Texas. This framework uses Microsoft's .NET technologies to provide a software development platform which allows for easy integration of COTS software tools with a flexible architecture that was specifically designed to support custom workflows based on existing drilling algorithms and technologies.

[0043] Referring to figure 1, a software architecture schematic is illustrated indicating the 'modular nature' for supporting custom workflows. Figure 1 schematically shows the modular architecture that was developed to support custom workflows. This provides the ability to configure the application based on the desired usage. For a quick estimation of the time, cost and risk associated with the well, a workflow consisting of lookup tables and simple algorithms can be selected. For a more detailed analysis, complex algorithms can be included in the workflow.

[0044] In addition to customizing the workflow, the software associated with the 'Automatic Well Planning Software System' was designed to use user-specified equipment catalogs for its analysis. This ensures that any results produced by the software are always based on local best practices and available equipment at the project site. From a usability perspective, application user interfaces were designed to allow the user to navigate through the workflow with ease.

[0045] Referring to figure 2, a typical task view consisting of workflow, help and data canvases is illustrated. Figure 2 shows a typical task view with its associated user canvases. A typical task view consists of a workflow task bar, a dynamically updating help canvas, and a combination of data canvases based on COTS tools like log graphics, Data Grids, Wellbore Schematic and charting tools. In any task, the user has the option to modify data through any of the canvases; the application then automatically synchronizes the data in the other canvases based on these user modifications.

[0046] The modular nature of the software architecture associated with the 'Automatic Well Planning Software System' also allows the setting-up of a non-graphical workflow, which is key to implementing advanced functionality, such as batch processing of an entire field, and sensitivity analysis based on key parameters, etc.

[0047] Basic information for a scenario, typical of well header information for the well and wellsite, is captured in the first task. The trajectory (measured depth, inclination, and azimuth) is loaded and the other directional parameters like true vertical depth and dogleg severity are calculated automatically and graphically presented to the user.

[0048] The 'Automatic Well Planning Software System' disclosed in this specification requires the loading of either geomechanical earth properties extracted from an earth model, or, at a minimum, pore pressure, fracture gradient, and unconfined compressive strength. From this input data, the 'Automatic Well Planning Software System' automatically selects the most appropriate rig and associated properties, costs, and mechanical capabilities. The rig properties include parameters like derrick rating to evaluate risks when running heavy casing strings, pump characteristics for the hydraulics, size of the BOP, which influences the sizes of the casings, and very importantly the daily rig rate and spread rate. The user can select a different rig than what the 'Automatic Well Planning Software System' proposed and can modify any of the technical specifications suggested by the software.

[0049] Other wellbore stability algorithms (which are offered by Schlumberger Technology Corporation, or Houston, Texas) calculate the predicted shear failure and the fracture pressure as a function of depth and display these values with the pore pressure. The 'Automatic Well Planning Software System' then proposes automatically the casing seats and maximum mud weight per hole section using customizable logic and rules. The rules include safety margins to the pore pressure and fracture gradient, minimum and maximum lengths for hole sections and limits for maximum overbalance of the drilling fluid to the pore pressure before a setting an additional casing point. The 'Automatic Well

Planning Software System' evaluates the casing seat selection from top-to-bottom and from bottom-to-top and determines the most economic variant. The user can change, insert, or delete casing points at any time, which will reflect in the risk, time, and cost for the well.

[0050] Referring to figure 3, a display showing wellbore stability, mud weights, and casing points is illustrated.

[0051] The wellbore sizes are driven primarily by the production tubing size. The preceding casing and hole sizes are determined using clearance factors. The wellbore sizes can be restricted by additional constraints, such as logging requirements or platform slot size. Casing weights, grades, and connection types are automatically calculated using traditional biaxial design algorithms and simple load cases for burst, collapse and tension. The most cost effective solution is chosen when multiple suitable pipes are found in the extensive tubular catalog. Non-compliance with the minimum required design factors are highlighted to the user, pointing out that a manual change of the proposed design may be in order. The 'Automatic Well Planning Software System' allows full strings to be replaced with liners, in which case, the liner overlap and hanger cost are automatically suggested while all strings are redesigned as necessary to account for changes in load cases. The cement slurries and placement are automatically proposed by the 'Automatic Well Planning Software System'. The lead and tail cement tops, volumes, and densities are suggested. The cementing hydrostatic pressures are validated against fracture pressures, while allowing the user to modify the slurry interval tops, lengths, and densities. The cost is derived from the volume of the cement job and length of time required to place the cement.

[0052] The 'Automatic Well Planning Software System' proposes the proper drilling fluid type including rheology properties that are required for hydraulic calculations. A sophisticated scoring system ranks the appropriate fluid systems, based on operating environment, discharge legislation, temperature, fluid density, wellbore stability, wellbore

friction and cost. The system is proposing not more than 3 different fluid systems for a well, although the user can easily override the proposed fluid systems.

[0053] A new and novel algorithm used by the 'Automatic Well Planning Software System' selects appropriate bit types that are best suited to the anticipated rock strengths, hole sizes, and drilled intervals. For each bit candidate, the footage and bit life is determined by comparing the work required to drill the rock interval with the statistical work potential for that bit. The most economic bit is selected from all candidates by evaluating the cost per foot which takes into account the rig rate, bit cost, tripping time and drilling performance (ROP). Drilling parameters like string surface revolutions and weight on bit are proposed based on statistical or historical data.

[0054] In the 'Automatic Well Planning Software System', the bottom hole assembly (BHA) and drillstring is designed based on the required maximum weight on bit, inclination, directional trajectory and formation evaluation requirements in the hole section. The well trajectory influences the relative weight distribution between drill collars and heavy weight drill pipe. The BHA components are automatically selected based on the hole size, the internal diameter of the preceding casings, and bending stress ratios are calculated for each component size transition. Final kick tolerances for each hole section are also calculated as part of the risk analysis.

[0055] The minimum flow rate for hole cleaning is calculated using Luo's[2] and Moore's[3] criteria considering the wellbore geometry, BHA configuration, fluid density and rheology, rock density, and ROP. The bit nozzles total flow area (TFA) are sized to maximize the standpipe pressure within the liner operating pressure envelopes. Pump liner sizes are selected based on the flow requirements for hole cleaning and corresponding circulating pressures. The Power Law rheology model is used to calculate the pressure drops through the circulating system, including the equivalent circulating density (ECD).

[0056] Referring to figure 4, a display showing 'Risk Assessment' is illustrated.

[0057] In figure 4, in the 'Automatic Well Planning Software System', drilling event 'risks' are quantified in a total of 54 risk categories of which the user can customize the risk thresholds. The risk categories are plotted as a function of depth and color coded to aid a quick visual interpretation of potential trouble spots. Further risk assessment is achieved by grouping these categories in the following categories: 'gains', 'losses', 'stuck pipe', and 'mechanical problems'. The total risk log curve can be displayed along the trajectory to correlate drilling risks with geological markers. Additional risk analysis views display the "actual risk" as a portion of the "potential risk" for each design task.

[0058] In the 'Automatic Well Planning Software System', a detailed operational activity plan is automatically assembled from customizable templates. The duration for each activity is calculated based on the engineered results of the previous tasks and Non-Productive Time (NPT) can be included. The activity plan specifies a range (minimum, average, and maximum) of time and cost for each activity and lists the operations sequentially as a function of depth and hole section. This information is graphically presented in the time vs depth and cost vs depth graphs.

[0059] Referring to figure 5, a display showing Monte Carlo time and cost distributions is illustrated. In figure 5, the 'Automatic Well Planning Software System' uses Monte Carlo simulation to reconcile all of the range of time and cost data to produce probabilistic time and cost distributions.

[0060] Referring to figure 6, a display showing Probabilistic time and cost vs. depth is illustrated. In figure 6, this probabilistic analysis, used by the 'Automatic Well Planning Software System' of the present invention, allows quantifying the P10, P50 and P90 probabilities for time and cost.

[0061] Referring to figure 7, a display showing a summary montage is illustrated. In figure 7, a comprehensive summary report and a montage display, utilized by the 'Automatic Well Planning Software System' of the present invention, can be printed or plotted in large scale and are also available as a standard result output.

[0062] Using its expert system and logic, the 'Automatic Well Planning Software System' disclosed in this specification automatically proposes sound technical solutions and provides a smooth path through the well planning workflow. Graphical interaction with the results of each task allows the user to efficiently fine-tune the results. In just minutes, asset teams, geoscientists, and drilling engineers can evaluate drilling projects and economics using probabilistic cost estimates based on solid engineering fundamentals instead of traditional, less rigorous estimation methods. The testing program combined with feedback received from other users of the program during the development of the software package made it possible to draw the following conclusions: (1) The 'Automatic Well Planning Software System' can be installed and used by inexperienced users with a minimum amount of training and by referencing the documentation provided, (2) The need for good earth property data enhances the link to geological and geomechanical models and encourages improved subsurface interpretation; it can also be used to quanitfy the value of acquiring additional information to reduce uncertainty, (3) With a minimum amount of input data, the 'Automatic Well Planning Software System' can create reasonable probabilistic time and cost estimates faithful to an engineered well design; based on the field test results, if the number of casing points and rig rates are accurate, the results will be within 20% of a fully engineered well design and AFE, (4) With additional customization and localization, predicted results compare to within 10% of a fully engineered well design AFE, (5) Once the 'Automatic Well Planning Software System' has been localized, the ability to quickly run new scenarios and assess the business impact and associated risks of applying new technologies, procedures or approaches to well designs is readily possible, (6) The speed of the 'Automatic Well Planning Software System' allows quick iteration and refinement of well plans and creation of different 'what if' scenarios for sensitivity analysis, (7) The 'Automatic Well Planning Software

System' provides consistent and transparent well cost estimates to a process that has historically been arbitrary, inconsistent, and opaque; streamlining the workflow and eliminating human bias provides drilling staff the confidence to delegate and empower non-drilling staff to do their own scoping estimates, (8) The 'Automatic Well Planning Software System' provides unique understanding of drilling risk and uncertainty enabling more realistic economic modeling and improved decision making, (9) The risk assessment accurately identifies the type and location of risk in the wellbore enabling drilling engineers to focus their detailed engineering efforts most effectively, (10) It was possible to integrate and automate the well construction planning workflow based on an earth model and produce technically sound usable results, (11) The project was able to extensively use COTS technology to accelerate development of the software, and (12) The well engineering workflow interdependencies were able to be mapped and managed by the software.

[0063] The following nomenclature was used in this specification:

RT =	Real-Time, usually used in the context of real-time data (while drilling).
G&G =	Geological and Geophysical
SEM =	Shared Earth Model
MEM =	Mechanical Earth Model
NPT =	Non Productive Time, when operations are not planned, or due to operational difficulties, the progress of the well has be delayed, also often referred to as Trouble Time.
NOT =	Non Optimum Time, when operations take longer than they should for various reasons.
WOB =	Weight on bit
ROP =	Rate of penetration
RPM =	Revolutions per minute
BHA =	Bottom hole assembly
SMR =	Software Modification Request
BOD =	Basis of Design, document specifying the requirements for a well to be drilled.
AFE =	Authorization for Expenditure

References

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(2) Luo, Y., Bern, P.A. and Chambers, B.D.: 'Flow-Rate Predictions for Cleaning Deviated Wells', paper IADC/SPE 23884 presented at the 1992 IADC/SPE Drilling Conference, New Orleans, Louisiana, February 18-21.

(3) Moore and Chien theory is published in 'Applied Drilling Engineering', Bourgoyne, A.T.,Jr, et al., SPE Textbook Series Vol2.

[0058] A functional specification associated with the overall 'Automatic Well Planning Software System' (termed a 'use case') will be set forth in the following paragraphs. This functional specification relates to the overall 'Automatic Well Planning Software System'.

[0059] The following defines information that pertains to this particular 'use case'. Each piece of information is important in understanding the purpose behind the 'use Case'.

Goal In Context:	Describe the full workflow for the low level user
Scope:	N/A
Level:	Low Level
Pre-Condition:	Geological targets pre-defined
Success End Condition:	Probability based time estimate with cost and risk
Failed End Condition:	Failure in calculations due to assumptions or if distribution of results is too large
Primary Actor:	Well Engineer
Trigger Event:	N/A

[0060] Main Success Scenario -- This Scenario describes the steps that are taken from trigger event to goal completion when everything works without failure. It also describes

any required cleanup that is done after the goal has been reached. The steps are listed below:

1. User opens program, and system prompts user whether to open an old file or create a new one. User creates new model and system prompts user for well information (well name, field, country, coordinates). System prompts user to insert earth model. Window with different options appears and user selects data level. Secondary window appears where file is loaded or data inserted manually. System displays 3D view of earth model with key horizons, targets, anti-targets, markers, seismic, etc.
2. System prompts user for a well trajectory. The user either loads from a file or creates one in Caviar for Swordfish. System generates 3D view of trajectory in the earth model and 2D views, both plan and vertical section. User prompted to verify trajectory and modify if needed via direct interaction with 3D window.
3. The system will extract mechanical earth properties (PP, FG, WBS, lithology, density, strength, min/max horizontal stress, etc.) for every point along the trajectory and store it. These properties will either come from a populated mechanical earth model, from interpreted logs applied to this trajectory, or manually entered.
4. The system will prompt the user for the rig constraints. Rig specification options will be offered and the user will choose either the type of rig and basic configurations or insert data manually for a specific drilling unit.
5. The system will prompt the user to enter pore pressure data, if applicable, otherwise taken from the mechanical earth model previously inserted and a MW window will be generated using PP, FG, and WBS curves. The MW window will be displayed and allow interactive modification.
6. The system will automatically divide the well into hole/casing sections based on kick tolerance and trajectory sections and then propose a mud weight schedule. These will be displayed on the MW window and allow the user to interactively

modify their values. The casing points can also be interactively modified on the 2D and 3D trajectory displays

7. The system will prompt the user for casing size constraints (tubing size, surface slot size, evaluation requirements), and based on the number of sections generate the appropriate hole size – casing size combinations. The hole/casing circle chart will be used, again allowing for interaction from the user to modify the hole/casing size progression.
8. The system will successively calculate casing grades, weights/wall thickness and connections based on the sizes selected and the depths. User will be able to interact and define availability of types of casing.
9. The system will generate a basic cementing program, with simple slurry designs and corresponding volumes..
10. The system will display the wellbore schematic based on the calculations previously performed and this interface will be fully interactive, allowing the user to click and drag hole & casing sizes, top & bottom setting depths, and recalculating based on these selections. System will flag user if the selection is not feasible.
11. The system will generate the appropriate mud types, corresponding rheology, and composition based on the lithology, previous calculations, and the users selection.
12. The system will successively split the well sections into bit runs, and based on the rock properties will select drilling bits for each section with ROP and drilling parameters.
13. The system will generate a basic BHA configuration, based on the bit section runs, trajectory and rock properties.

Items 14, 15, and 16 represent one task: Hydraulics.

14. The system will run a hole cleaning calculation, based on trajectory, wellbore geometry, BHA composition and MW characteristics.

15. The system will do an initial hydraulics/ECD calculation using statistical ROP data. This data will be either selected or user defined by the system based on smart table lookup.

16. Using the data generated on the first hydraulics calculation, the system will perform an ROP simulation based on drilling bit characteristics and rock properties.

17. The system will run a successive hydraulics/ECD calculation using the ROP simulation data. System will flag user if parameters are not feasible.

18. The system will calculate the drilling parameters and display them on a multi display panel. This display will be exportable, portable, and printable.

19. The system will generate an activity planning sequence using default activity sequences for similar hole sections and end conditions. This sequence will be fully modifiable by the user, permitting modification in sequence order and duration of the event. This sequence will be in the same standard as the Well Operations or Drilling Reporting software and will be interchangeable with the Well Operations or Drilling Reporting software. The durations of activities will be populated from tables containing default "best practice" data or from historical data (DIMS, Snapper…).

20. The system will generate time vs. depth curve based on the activity planning details. The system will create a best, mean, and worst set of time curves using combinations of default and historical data. These curves will be exportable to other documents and printable.

21. The system will prompt the user to select probability points such as P10, P50, P90 and then run a Monte Carlo simulation to generate a probability distribution curve for the scenario highlighting the user selected reference points and corresponding values of time. The system will provide this as frequency data or cumulative probability curves. These curves will be again exportable and printable.

22. The system will generate a cost plan using default cost templates that are pre-configured by users and can be modified at this point. Many of the costs will reference durations of the entire well, hole sections, or specific activities to

calculate the applied cost. The system will generate P10, P50, and P90 cost vs. depth curves.

23. The system will generate a summary of the well plan, in word format, along with the main display graphs. The user will select all that should be exported via a check box interface. The system will generate a large one-page summary of the whole process. This document will be as per a standard Well Operations Program template.

[0061] Referring to figure 8, as can be seen on the left side of the displays illustrated in figures 2 through 6, the 'Automatic Well Planning Software System' includes a plurality of tasks. Each of those tasks are illustrated in figure 8. In figure 8, those plurality of tasks are divided into four groups: (1) Input task 10, where input data is provided, (2) Wellbore Geometry task 12 and Drilling Parameters task 14, where calculations are performed, and (3) a Results task 16, where a set of results are calculated and presented to a user. The Input task 10 includes the following sub-tasks: (1) scenario information, (2) trajectory, (3) Earth properties, (4) Rig selection, (5) Resample Data. The Wellbore Geometry task 12 includes the following sub-tasks: (1) Wellbore stability, (2) Mud weights and casing points, (3) Wellbore sizes, (4) Casing design, (5) Cement design, (6) Wellbore geometry. The Drilling Parameters task 14 includes the following sub-tasks: (1) Drilling fluids, (2) Bit selection 14a, (3) Drillstring design 14b, (4) Hydraulics. The Results task 16 includes the following sub-tasks: (1) Risk Assessment 16a, (2) Risk Matrix, (3) Time and cost data, (4) Time and cost chart, (5) Monte Carlo, (6) Monte Carlo graph, (7) Summary report, and (8) montage.

[0062] Recalling that the Results task 16 of figure 8 includes a 'Risk Assessment' sub-task 16a, the 'Risk Assessment' sub-task 16a will be discussed in detail in the following paragraphs with reference to figures 9A, 9B, and 10.

<u>Automatic Well Planning Software System – Risk Assessment sub-task 16a - Software</u>

[0063] Identifying the risks associated with drilling a well is probably the most subjective process in well planning today. This is based on a person recognizing part of a technical well design that is out of place relative to the earth properties or mechanical equipment to be used to drill the well. The identification of any risks is brought about by integrating all of the well, earth, and equipment information in the mind of a person and mentally sifting through all of the information, mapping the interdependencies, and based solely on personal experience extracting which parts of the project pose what potential risks to the overall success of that project. This is tremendously sensitive to human bias, the individual's ability to remember and integrate all of the data in their mind, and the individuals experience to enable them to recognize the conditions that trigger each drilling risk. Most people are not equipped to do this and those that do are very inconsistent unless strict process and checklists are followed. There are some drilling risk software systems in existence today, but they all require the same human process to identify and assess the likelihood of each individual risks and the consequences. They are simply a computer system for manually recording the results of the risk identification process.

[0064] The Risk Assessment sub-task 16a associated with the 'Automatic Well Planning Software System' of the present invention is a system that will automatically assess risks associated with the technical well design decisions in relation to the earth's geology and geomechanical properties and in relation to the mechanical limitations of the equipment specified or recommended for use.

[0065] Risks are calculated in four ways: (1) by 'Individual Risk Parameters', (2) by 'Risk Categories', (3) by 'Total Risk', and (4) the calculation of 'Qualitative Risk Indices' for each.

[0066] Individual Risk Parameters are calculated along the measured depth of the well and color coded into high, medium, or low risk for display to the user. Each risk will identify to the user: an explanation of exactly what is the risk violation, and the value and the task in the workflow controlling the risk. These risks are calculated consistently and transparently allowing users to see and understand all of the known risks and how they are identified. These risks also tell the users which aspects of the well justify further engineering effort to investigate in more detail.

[0067] Group/category risks are calculated by incorporating all of the individual risks in specific combinations. Each individual risk is a member of one or more Risk Categories. Four principal Risk Categories are defined as follows: (1) Gains, (2) Losses, (3) Stuck, and (4) Mechanical; since these four Rick Categories are the most common and costly groups of troublesome events in drilling worldwide.

[0068] The Total Risk for a scenario is calculated based on the cumulative results of all of the group/category risks along both the risk and depth axes.

[0069] Risk indexing - Each individual risk parameter is used to produce an individual risk index which is a relative indicator of the likelihood that a particular risk will occur. This is purely qualitative, but allows for comparison of the relative likelihood of one risk to another – this is especially indicative when looked at from a percentage change. Each Risk Category is used to produce a category risk index also indicating the likelihood of occurrence and useful for identifying the most likely types of trouble events to expect. Finally, a single risk index is produced for the scenario that is specifically useful for comparing the relative risk of one scenario to another.

[0070] The 'Automatic Well Planning Software System' of the present invention is capable of delivering a comprehensive technical risk assessment, and it can do this automatically. Lacking an integrated model of the technical well design to relate design decisions to associated risks, the 'Automatic Well Planning Software System' can

attribute the risks to specific design decisions and it can direct users to the appropriate place to modify a design choice in efforts to modify the risk profile of the well.

[0071] Referring to figure 9A, a Computer System 18 is illustrated. The Computer System 18 includes a Processor 18a connected to a system bus, a Recorder or Display Device 18b connected to the system bus, and a Memory or Program Storage Device 18c connected to the system bus. The Recorder or Display Device 18b is adapted to display 'Risk Assessment Output Data' 18b1. The Memory or Program Storage Device 18c is adapted to store an 'Automatic Well Planning Risk Assessment Software' 18c1. The 'Automatic Well Planning Risk Assessment Software' 18c1 is originally stored on another 'program storage device', such as a hard disk; however, the hard disk was inserted into the Computer System 18 and the 'Automatic Well Planning Risk Assessment Software' 18c1 was loaded from the hard disk into the Memory or Program Storage Device 18c of the Computer System 18 of figure 9A. In addition, a Storage Medium 20 containing a plurality of 'Input Data' 20a is adapted to be connected to the system bus of the Computer System 18, the 'Input Data' 20a being accessible to the Processor 18a of the Computer System 18 when the Storage Medium 20 is connected to the system bus of the Computer System 18. In operation, the Processor 18a of the Computer System 18 will execute the Automatic Well Planning Risk Assessment Software 18c1 stored in the Memory or Program Storage Device 18c of the Computer System 18 while, simultaneously, using the 'Input Data' 20a stored in the Storage Medium 20 during that execution. When the Processor 18a completes the execution of the Automatic Well Planning Risk Assessment Software 18c1 stored in the Memory or Program Storage Device 18c (while using the 'Input Data' 20a), the Recorder or Display Device 18b will record or display the 'Risk Assessment Output Data' 18b1, as shown in figure 9A. For example the 'Risk Assessment Output Data' 18b1 can be displayed on a display screen of the Computer System 18, or the 'Risk Assessment Output Data' 18b1 can be recorded on a printout which is generated by the Computer System 18. The Computer System 18 of figure 9A may be a personal computer (PC). The Memory or Program Storage Device 18c is a computer readable medium or a program storage device

which is readable by a machine, such as the processor 18a. The processor 18a may be, for example, a microprocessor, microcontroller, or a mainframe or workstation processor. The Memory or Program Storage Device 18c, which stores the 'Automatic Well Planning Risk Assessment Software' 18c1, may be, for example, a hard disk, ROM, CD-ROM, DRAM, or other RAM, flash memory, magnetic storage, optical storage, registers, or other volatile and/or non-volatile memory.

[0072] Referring to figure 9B, a larger view of the Recorder or Display Device 18b of figure 9A is illustrated. In figure 9B, the 'Risk Assessment Output Data' 18b1 includes: (1) a plurality or Risk Categories, (2) a plurality of Subcategory Risks (each of which have been ranked as either a High Risk or a Medium Risk or a Low Risk), and (3) a plurality of Individual Risks (each of which have been ranked as either a High Risk or a Medium Risk or a Low Risk). The Recorder or Display Device 18b of figure 9B will display or record the 'Risk Assessment Output Data' 18b1 including the Risk Categories, the Subcategory Risks, and the Individual Risks.

[0073] Referring to figure 10, a detailed construction of the 'Automatic Well Planning Risk Assessment Software' 18c1 of figure 9A is illustrated. In figure 10, the 'Automatic Well Planning Risk Assessment Software' 18c1 includes a first block which stores the Input Data 20a, a second block 22 which stores a plurality of Risk Assessment Logical Expressions 22; a third block 24 which stores a plurality of Risk Assessment Algorithms 24, a fourth block 26 which stores a plurality of Risk Assessment Constants 26, and a fifth block 28 which stores a plurality of Risk Assessment Catalogs 28. The Risk Assessment Constants 26 include values which are used as input for the Risk Assessment Algorithms 24 and the Risk Assessment Logical Expressions 22. The Risk Assessment Catalogs 28 include look-up values which are used as input by the Risk Assessment Algorithms 24 and the Risk Assessment Logical Expressions 22. The 'Input Data' 20a includes values which are used as input for the Risk Assessment Algorithms 24 and the Risk Assessment Logical Expressions 22. The 'Risk Assessment Output Data' 18b1 includes values which are computed by the Risk Assessment Algorithms 24 and which

result from the Risk Assessment Logical Expressions 22. In operation, referring to figures 9 and 10, the Processor 18a of the Computer System 18 of figure 9A executes the Automatic Well Planning Risk Assessment Software 18c1 by executing the Risk Assessment Logical Expressions 22 and the Risk Assessment Algorithms 24 of the Risk Assessment Software 18c1 while, simultaneously, using the 'Input Data' 20a, the Risk Assessment Constants 26, and the values stored in the Risk Assessment Catalogs 28 as 'input data' for the Risk Assessment Logical Expressions 22 and the Risk Assessment Algorithms 24 during that execution. When that execution by the Processor 18a of the Risk Assessment Logical Expressions 22 and the Risk Assessment Algorithms 24 (while using the 'Input Data' 20a, Constants 26, and Catalogs 28) is completed, the 'Risk Assessment Output Data' 18b1 will be generated as a 'result'. That 'Risk Assessment Output Data' 18b1 is recorded or displayed on the Recorder or Display Device 18b of the Computer System 18 of figure 9A. In addition, that 'Risk Assessment Output Data' 18b1 can be manually input, by an operator, to the Risk Assessment Logical Expressions block 22 and the Risk Assessment Algorithms block 24 via a 'Manual Input' block 30 shown in figure 10.

<u>Input Data 20a</u>

[0074] The following paragraphs will set forth the 'Input Data' 20a which is used by the 'Risk Assessment Logical Expressions' 22 and the 'Risk Assessment Algorithms' 24. Values of the Input Data 20a that are used as input for the Risk Assessment Algorithms 24 and the Risk Assessment Logical Expressions 22 are as follows:

(1) Casing Point Depth
(2) Measured Depth
(3) True Vertical Depth
(4) Mud Weight
(5) Measured Depth
(6) ROP
(7) Pore Pressure
(8) Static Temperature
(9) Pump Rate

(10) Dog Leg Severity
(11) ECD
(12) Inclination
(13) Hole Size
(14) Casing Size
(15) Easting-westing
(16) Northing-Southing
(17) Water Depth
(18) Maximum Water Depth
(19) Maximum well Depth
(20) Kick Tolerance
(21) Drill Collar 1 Weight
(22) Drill Collar 2Weight
(23) Drill Pipe Weight
(24) Heavy Weight Weight
(25) Drill Pipe Tensile Rating
(26) Upper Wellbore Stability Limit
(27) Lower Wellbore Stability Limit
(28) Unconfined Compressive Strength
(29) Bit Size
(30) Mechanical drilling energy (UCS integrated over distance drilled by the bit)
(31) Ratio of footage drilled compared to statistical footage
(32) Cumulative UCS
(33) Cumulative Excess UCS
(34) Cumulative UCS Ratio
(35) Average UCS of rock in section
(36) Bit Average UCS of rock in section
(37) Statistical Bit Hours
(38) Statistical Drilled Footage for the bit
(39) RPM
(40) On Bottom Hours
(41) Calculated Total Bit Revolutions
(42) Time to Trip
(43) Critical Flow Rate
(44) Maximum Flow Rate in hole section
(45) Minimum Flow Rate in hole section
(46) Flow Rate
(47) Total Nozzle Flow Area of bit
(48) Top Of Cement
(49) Top of Tail slurry
(50) Length of Lead slurry
(51) Length of Tail slurry
(52) Cement Density Of Lead
(53) Cement Density Of Tail slurry
(54) Casing Weight per foot

(55) Casing Burst Pressure
(56) Casing Collapse Pressure
(57) Casing Type Name
(58) Hydrostatic Pressure of Cement column
(59) Start Depth
(60) End Depth
(61) Conductor
(62) Hole Section Begin Depth
(63) Openhole Or Cased hole completion
(64) Casing Internal Diameter
(65) Casing Outer Diameter
(66) Mud Type
(67) Pore Pressure without Safety Margin
(68) Tubular Burst Design Factor
(69) Casing Collapse Pressure Design Factor
(70) Tubular Tension Design Factor
(71) Derrick Load Rating
(72) Drawworks Rating
(73) Motion Compensator Rating
(74) Tubular Tension rating
(75) Statistical Bit ROP
(76) Statistical Bit RPM
(77) Well Type
(78) Maximum Pressure
(79) Maximum Liner Pressure Rating
(80) Circulating Pressure
(81) Maximum UCS of bit
(82) Air Gap
(83) Casing Point Depth
(84) Presence of H2S
(85) Presence of CO2
(86) Offshore Well
(87) Flow Rate Maximum Limit

Risk Assessment Constants 26

[0075] The following paragraphs will set forth the 'Risk Assessment Constants' 26 which are used by the 'Risk Assessment Logical Expressions' 22 and the 'Risk Assessment Algorithms' 24. Values of the Constants 26 that are used as input data for Risk Assessment Algorithms 24 and the Risk Assessment Logical Expressions 22 are as follows:

(1) Maximum Mud Weight Overbalance to Pore Pressure
(2) Minimum Required Collapse Design Factor
(3) Minimum Required Tension Design Factor
(4) Minimum Required Burst Design Factor
(5) Rock density
(6) Seawater density

Risk Assessment Catalogs 28

[0076] The following paragraphs will set forth the 'Risk Assessment Catalogs' 28 which are used by the 'Risk Assessment Logical Expressions' 22 and the 'Risk Assessment Algorithms' 24. Values of the Catalogs 28 that are used as input data for Risk Assessment Algorithms 24 and the Risk Assessment Logical Expressions 22 include the following:

(1) Risk Matrix Catalog
(2) Risk Calculation Catalog
(3) Drillstring component catalog
(4) Drill Bit Catalog
(5) Clearance Factor Catalog
(6) Drill Collar Catalog
(7) Drill Pipes Catalog
(8) Minimum and maximum flow rate catalog
(9) Pump catalog
(10) Rig Catalog
(11) Constants and variables Settings catalog
(12) Tubular Catalog

Risk Assessment Output Data 18b1

[0077] The following paragraphs will set forth the 'Risk Assessment Output Data' 18b1 which are generated by the 'Risk Assessment Algorithms' 24. The 'Risk Assessment Output Data' 18b1, which is generated by the 'Risk Assessment Algorithms' 24, includes the following types of output data: (1) Risk Categories, (2) Subcategory Risks, and (3) Individual Risks. The 'Risk Categories', 'Subcategory Risks', and 'Individual Risks' included within the 'Risk Assessment Output Data' 18b1 comprise the following:

The following 'Risk Categories' are calculated:

(1) Individual Risk
(2) Average Individual Risk
(3) Subcategory Risk
(4) Average Subcategory Risk
(5) Total risk
(6) Average total risk
(7) Potential risk for each design task
(8) Actual risk for each design task

The following 'Subcategory Risks' are calculated

(1) Gains risks
(2) Losses risks
(3) Stuck Pipe risks
(4) Mechanical risks

The following 'Individual Risks' are calculated

(1) H2S and CO2,
(2) Hydrates,
(3) Well water depth,
(4) Tortuosity,
(5) Dogleg severity,
(6) Directional Drilling Index,
(7) Inclination,
(8) Horizontal displacement,
(9) Casing Wear,
(10) High pore pressure,
(11) Low pore pressure,
(12) Hard rock,
(13) Soft Rock,
(14) High temperature,
(15) Water-depth to rig rating,
(16) Well depth to rig rating,
(17) mud weight to kick,
(18) mud weight to losses,
(19) mud weight to fracture,
(20) mud weight window,
(21) Wellbore stability window,
(22) wellbore stability,
(23) Hole section length,

(24) Casing design factor,
(25) Hole to casing clearance,
(26) casing to casing clearance,
(27) casing to bit clearance,
(28) casing linear weight,
(29) Casing maximum overpull,
(30) Low top of cement,
(31) Cement to kick,
(32) cement to losses,
(33) cement to fracture,
(34) Bit excess work,
(35) Bit work,
(36) Bit footage,
(37) bit hours,
(38) Bit revolutions,
(39) Bit ROP,
(40) Drillstring maximum overputt,
(41) Bit compressive strength,
(42) Kick tolerance,
(43) Critical flow rate,
(44) Maximum flow rate,
(45) Small nozzle area,
(46) Standpipe pressure,
(47) ECD to fracture,
(48) ECD to losses,
(49) Subsea BOP,
(50) Large Hole,
(51) Small Hole,
(52) Number of casing strings,
(53) Drillstring parting,
(54) Cuttings.

Risk Assessment Logical Expressions 22

[0078] The following paragraphs will set forth the 'Risk Assessment Logical Expressions' 22. The 'Risk Assessment Logical Expressions' 22 will: (1) receive the 'Input Data 20a' including a 'plurality of Input Data calculation results' that has been generated by the 'Input Data 20a'; (2) determine whether each of the 'plurality of Input Data calculation results' represent a high risk, a medium risk, or a low risk; and (3) generate a 'plurality of Risk Values' (also known as a 'plurality of Individual Risks), in

response thereto, each of the plurality of Risk Values/plurality of Individual Risks representing a 'an Input Data calculation result' that has been 'ranked' as either a 'high risk', a 'medium risk', or a 'low risk'.

[0079] The Risk Assessment Logical Expressions 22 include the following:

Task: Scenario
Description: H2S and CO2 present for scenario indicated by user (per well)
Short Name: H2S_CO2
Data Name: H2S
Calculation: H2S and CO2 check boxes checked yes
Calculation Name: CalculateH2S_CO2
High: Both selected
Medium: Either one selected
Low: Neither selected
Unit: unitless

Task: Scenario
Description: Hydrate development (per well)
Short Name: Hydrates
Data Name: Water Depth
Calculation: = Water Depth
Calculation Name: CalculateHydrates
High: >= 3000
Medium: >= 2000
Low: < 2000
Unit: ft

Task: Scenario
Description: Hydrate development (per well)
Short Name: Well_WD
Data Name: Water Depth
Calculation: = WaterDepth
Calculation Name: CalculateHydrates
High: >= 5000
Medium: >= 1000
Low: < 1000
Unit: ft

Task: Trajectory
Description: Dogleg severity (per depth)
Short Name: DLS

Data Name: Dog Leg Severity
Calculation: NA
Calculation Name: CalculateRisk
High: >= 6
Medium: >= 4
Low: < 4
Unit: deg/100ft

Task: Trajectory
Description: Tortuosity (per depth)
Short Name: TORT
Data Name: Dog Leg Severity
Calculation: Summation of DLS
Calculation Name: CalculateTort
High: >= 90
Medium: >= 60
Low: < 60
Unit: deg

Task: Trajectory
Description: Inclination (per depth)
Short Name: INC
Data Name: Inclination
Calculation: NA
Calculation Name: CalculateRisk
High: >= 65
Medium: >= 40
Low: < 40
Unit: deg

Task: Trajectory
Description: Well inclinations with difficult cuttings transport conditions (per depth)
Short Name: Cutting
Data Name: Inclination
Calculation: NA
Calculation Name: CalculateCutting
High: >= 45
Medium: > 65
Low: < 45
Unit: deg

Task: Trajectory
Description: Horizontal to vertical ratio (per depth)
Short Name: Hor_Disp
Data Name: Inclination

Calculation: = Horizontal Displacement /True Vertical Depth
Calculation Name: CalculateHor Disp
High: >= 1.0
Medium: >= 0.5
Low: < 0.5
Unit: Ratio

Task: Trajectory
Description: Directional Drillability Index (per depth) Fake Threshold
Short Name: DDI
Data Name: Inclination
Calculation: = Calculate DDI using Resample data
Calculation Name: CalculateDDI
High: > 6.8
Medium: >= 6.0
Low: < 6.0
Unit: unitless

Task: EarthModel
Description: High or supernormal Pore Pressure (per depth)
Short Name: PP_High
Data Name: Pore Pressure without Safety Margin
Calculation: = PP
Calculation Name: CalculateRisk
High: >= 16
Medium: >= 12
Low: < 12
Unit: ppg

Task: EarthModel
Description: Depleted or subnormal Pore Pressure (per depth)
Short Name: PP_Low
Data Name: Pore Pressure without Safety Margin
Calculation: = Pore Pressure without Safety Margin
Calculation Name: CalculateRisk
High: <= 8.33
Medium: <= 8.65
Low: > 8.65
Unit: ppg

Task: EarthModel
Description: Superhard rock (per depth)
Short Name: RockHard
Data Name: Unconfined Compressive Strength
Calculation: = Unconfined Compressive Strength

Calculation Name: CalculateRisk
High: >= 25
Medium: >= 16
Low: < 16
Unit: kpsi

Task: EarthModel
Description: Gumbo (per depth)
Short Name: RockSoft
Data Name: Unconfined Compressive Strength
Calculation: = Unconfined Compressive Strength
Calculation Name: CalculateRisk
High: <= 2
Medium: <= 4
Low: > 4
Unit: kpsi

Task: EarthModel
Description: High Geothermal Temperature (per depth)
Short Name: TempHigh
Data Name: StaticTemperature
Calculation: = Temp
Calculation Name: CalculateRisk
High: >= 280
Medium: >= 220
Low: < 220
Unit: degF

Task: RigConstraint
Description: Water depth as a ratio to the maximum water depth rating of the rig (per depth)
Short Name: Rig_WD
Data Name:
Calculation: = WD , Rig WD rating
Calculation Name: CalculateRig_WD
High: >= 0.75
Medium: >= 0.5
Low: < 0.5
Unit: Ratio

Task: RigConstraint
Description: Total measured depth as a ratio to the maximum depth rating of the rig (per depth)
Short Name: Rig_MD
Data Name:

Calculation: = MD /Rig MD rating
Calculation Name: CalculateRig_MD
High: >= 0.75
Medium: >= 0.5
Low: < 0.5
Unit: Ratio

Task: RigConstraint
"Description: Subsea BOP or wellhead (per well), not quite sure how to compute it"
Short Name: SS_BOP
Data Name: Water Depth
Calculation: =
Calculation Name: CalculateHydrates
High: >= 3000
Medium: >= 1000
Low: < 1000
Unit: ft

Task: MudWindow
Description: Kick potential where Mud Weight is too low relative to Pore Pressure (per depth)
Short Name: MW_Kick
Data Name:
Calculation: = Mud Weight – Pore Pressure
Calculation Name: CalculateMW_Kick
High: <= 0.3
Medium: <= 0.5
Low: > 0.5
Unit: ppg

Task: MudWindow
Description: Loss potential where Hydrostatic Pressure is too high relative to Pore Pressure (per depth)
Short Name: MW_Loss
Data Name:
Calculation: = Hydrostatic Pressure – Pore Pressure
Calculation Name: CalculateMW_Loss
"PreCondition: =Mud Type (HP-WBM, ND-WBM, D-WBM)"
High: >= 2500
Medium: >= 2000
Low: < 2000
Unit: psi

Task: MudWindow

Description: Loss potential where Hydrostatic Pressure is too high relative to Pore Pressure (per depth)
Short Name: MW_Loss
Data Name:
Calculation: = Hydrostatic Pressure – Pore Pressure
Calculation Method: CalculateMW_Loss
"PreCondition: =Mud Type (OBM, MOBM, SOBM)"
High: >= 2000
Medium: >= 1500
Low: < 1500
Unit: psi

Task: MudWindow
Description: Loss potential where Mud Weight is too high relative to Fracture Gradient (per depth)
Short Name: MW_Frac
Data Name:
Calculation: = Upper Bound – Mud Weight
Calculation Method: CalculateMW_Frac
High: <= 0.2
Medium: <= 0.5
Low: > 0.5
Unit: ppg

Task: MudWindow
Description: Narrow mud weight window (per depth)
Short Name: MWW
Data Name:
Calculation: = Upper Wellbore Stability Limit – Pore Pressure without Safety Margin
Calculation Method: CalculateMWW
High: <= 0.5
Medium: <= 1.0
Low: > 1.0
Unit: ppg

Task: MudWindow
Description: Narrow wellbore stability window (per depth)
Short Name: WBSW
Data Name:
Calculation: = Upper Bound – Lower Bound
Calculation Method: CalculateWBSW
"PreCondition: =Mud Type (OBM, MOBM, SOBM)"
High: <= 0.3
Medium: <= 0.6
Low: > 0.6

Unit: ppg

Task: MudWindow
Description: Narrow wellbore stability window (per depth)
Short Name: WBSW
Data Name:
Calculation: = Upper Bound – Lower Bound
Calculation Method: CalculateWBSW
"PreCondition: =Mud Type (HP-WBM, ND-WBM, D-WBM)"
High: <= 0.4
Medium: <= 0.8
Low: > 0.8
Unit: ppg

Task: MudWindow
Description: Wellbore Stability (per depth)
Short Name: WBS
Data Name: Pore Pressure without Safety Margin
Calculation: = Pore Pressure without Safety Margin
Calculation Method: CalculateWBS
High: LB >= MW >= PP
Medium: MW >= LB >= PP
Low: MW >= PP >= LB
Unit: unitless

Task: MudWindow
Description: Hole section length (per hole section)
Short Name: HSLength
Data Name:
Calculation: = HoleEnd - HoleStart
Calculation Method: CalculateHSLength
High: >= 8000
Medium: >= 7001
Low: < 7001
Unit: ft

Task: MudWindow
Description: Dogleg severity at Casing points for casing wear (per hole section)
Short Name: Csg_Wear
Data Name: Dog Leg Severity
Calculation: = Hole diameter
Calculation Method: CalculateCsg_Wear
High: >= 4
Medium: >= 3
Low: < 3

Unit: deg/100ft

Task: MudWindow
Description: Number of Casing strings (per hole section)
Short Name: Csg_Count
Data Name: Casing Point Depth
Calculation: = Number of Casing strings
Calculation Method: CalculateCsg_Count
High: >= 6
Medium: >= 4
Low: < 4
Unit: unitless

Task: WellboreSizes
Description: Large Hole size (per hole section)
Short Name: Hole_Big
Data Name: Hole Size
Calculation: = Hole diameter
Calculation Method: CalculateHoleSectionRisk
High: >= 24
Medium: >= 18.625
Low: < 18.625
Unit: in

Task: WellboreSizes
Description: Small Hole size (per hole section)
Short Name: Hole_Sm
Data Name: Hole Size
Calculation: = Hole diameter
Calculation Method: CalculateHole_Sm
PreCondition: Onshore
High: <= 4.75
Medium: <= 6.5
Low: > 6.5
Unit: in

Task: WellboreSizes
Description: Small Hole size (per hole section)
Short Name: Hole_Sm
Data Name: Hole Size
Calculation: = Hole diameter
Calculation Method: CalculateHole_Sm
PreCondition: Offshore
High: <= 6.5
Medium: <= 7.875

Low: > 7.875
Unit: in

Task: TubularDesign
"Description: Casing Design Factors for Burst, Collapse, & Tension (per hole section), DFb,c,t <= 1.0 for High, DFb,c,t <= 1.1 for Medium, DFb,c,t > 1.1 for Low"
Short Name: Csg_DF
Data Name:
Calculation: = DF/Design Factor
Calculation Method: CalculateCsg_DF
High: <= 1.0
Medium: <= 1.1
Low: > 1.1
Unit: unitless

Task: TubularDesign
Description: Casing string weight relative to rig lifting capabilities (per casing string)
Short Name: Csg_Wt
Data Name:
Calculation: = CasingWeight/RigMinRating
Calculation Method: CalculateCsg_Wt
High: >= 0.95
Medium: < 0.95
Low: < 0.8
Unit: Ratio

Task: TubularDesign
Description: Casing string allowable Margin of Overpull (per casing string)
Short Name: Csg_MOP
Data Name:
Calculation: = Tubular Tension rating-CasingWeight
Calculation Method: CalculateCsg_MOP
High: <= 50
Medium: <= 100
Low: > 100
Unit: klbs

Task: WellboreSizes
Description: Clearance between hole size and casing max OD (per hole section)
Short Name: Hole_Csg
Data Name:
Calculation: = Area of hole size , Area of casing size (max OD)
Calculation Method: CalculateHole_Csg
High: <= 1.1
Medium: <= 1.25

Low: > 1.25
Unit: Ratio

Task: WellboreSizes
Description:
Short Name: Csg_Csg
Data Name:
Calculation: = CainsgID/NextMaxCasingSize
Calculation Method: CalculateCsg_Csg
High: <= 1.05
Medium: <= 1.1
Low: > 1.1
Unit: Ratio

Task: WellboreSizes
Description: Clearance between casing inside diameter and subsequent bit size (per bit run)
Short Name: Csg_Bit
Data Name:
Calculation: = CainsgID/NextBit Size
Calculation Method: CalculateCsg_Bit
High: <= 1.05
Medium: <= 1.1
Low: > 1.1
Unit: Ratio

Task: CementDesign
Description: Cement height relative to design guidelines for each string type (per hole section)
Short Name: TOC_Low
Data Name:
Calculation: = CasingBottomDepth - TopDepthOfCement
Calculation Method: CalculateTOC_Low
High: <= 0.75
Medium: <= 1.0
Low: > 1.0
Unit: Ratio

Task: CementDesign
Description: Kick potential where Hydrostatic Pressure is too low relative to Pore Pressure (per depth)
Short Name: Cmt_Kick
Data Name:
Calculation: = (Cementing Hydrostatic Pressure – Pore Pressure)/TVD
Calculation Method: CalculateCmt_Kick

High: <= 0.3
Medium: <= 0.5
Low: > 0.5
Unit: ppg

Task: CementDesign
Description: Loss potential where Hydrostatic Pressure is too high relative to Pore Pressure (per depth)
Short Name: Cmt_Loss
Data Name:
Calculation: = Cementing Hydrostatic Pressure – Pore Pressure
Calculation Method: CalculateCmt_Loss
High: >= 2500
Medium: >= 2000
Low: < 2000
Unit: psi

Task: CementDesign
Description: Loss potential where Hydrostatic Pressure is too high relative to Fracture Gradient (per depth)
Short Name: Cmt_Frac
Data Name:
Calculation: = (UpperBound - Cementing Hydrostatic Pressure)/TVD
Calculation Method: CalculateCmt_Frac
High: <= 0.2
Medium: <= 0.5
Low: > 0.5
Unit: ppg

Task: BitsSelection
Description: Excess bit work as a ratio to the Cumulative Mechanical drilling energy (UCS integrated over distance drilled by the bit)
Short Name: Bit_WkXS
Data Name: CumExcessCumulative UCSRatio
Calculation: = CumExcess/Cumulative UCS
Calculation Method: CalculateBitSectionRisk
High: >= 0.2
Medium: >= 0.1
Low: < 0.1
Unit: Ratio

Task: BitsSelection
Description: Cumulative bit work as a ratio to the bit catalog average Mechanical drilling energy (UCS integrated over distance drilled by the bit)
Short Name: Bit_Wk

Data Name:
Calculation: = Cumulative UCS/ Mechanical drilling energy (UCS integrated over distance drilled by the bit)
Calculation Method: CalculateBit_Wk
High: >= 1.5
Medium: >= 1.25
Low: < 1.25
Unit: Ratio

Task: BitsSelection
Description: Cumulative bit footage as a ratio to the bit catalog average footage (drilled length) (per depth)
Short Name: Bit_Ftg
Data Name: Ratio of footage drilled compared to statistical footage
Calculation: = Ratio of footage drilled compared to statistical footage
Calculation Method: CalculateBitSectionRisk
High: >= 2
Medium: >= 1.5
Low: < 1.5
Unit: Ratio

Task: BitsSelection
Description: Cumulative bit hours as a ratio to the bit catalog average hours (on bottom rotating time) (per depth)
Short Name: Bit_Hrs
Data Name: Bit_Ftg
Calculation: = On Bottom Hours/Statistical Bit Hours
Calculation Method: CalculateBit_Hrs
High: >= 2
Medium: >= 1.5
Low: < 1.5
Unit: Ratio

Task: BitsSelection
Description: Cumulative bit Krevs as a ratio to the bit catalog average Krevs (RPM*hours) (per depth)
Short Name: Bit_Krev
Data Name:
Calculation: = Cumulative Krevs , Bit average Krevs
Calculation Method: CalculateBit_Krev
High: >= 2
Medium: >= 1.5
Low: < 1.5
Unit: Ratio

Task: BitsSelection
Description: Bit ROP as a ratio to the bit catalog average ROP (per bit run)
Short Name: Bit_ROP
Data Name:
Calculation: = ROP/Statistical Bit ROP
Calculation Method: CalculateBit_ROP
High: >= 1.5
Medium: >= 1.25
Low: < 1.25
Unit: Ratio

Task: BitsSelection
Description: UCS relative to Bit UCS and Max Bit UCS (per depth)
Short Name: Bit_UCS
Data Name:
Calculation: = UCS
Calculation Method: CalculateBit_UCS
High: UCS >= Max Bit UCS >= Bit UCS
Medium: Max Bit UCS >= UCS >= Bit UCS
Low: Max Bit UCS >= Bit UCS >= UCS
Unit: Ratio

Task: DrillstringDesign
Description: Drillstring allowable Margin of Overpull (per bit run)
Short Name: DS_MOP
Data Name:
Calculation: = MOP
Calculation Method: CalculateDS_MOP
High: <= 50
Medium: <= 100
Low: > 100
Unit: klbs

Task: DrillstringDesign
"Description: Potential parting of the drillstrings where required tension approaches mechanical tension limits of drill pipe, heavy weight, drill pipe, drill collars, or connections (per bit run) "
Short Name: DS_Part
Data Name:
Calculation: = Required Tension (including MOP)/Tension limit of drilling component (DP)
Calculation Method: CalculateDS_Part
High: >= 0.9
Medium: >= 0.8
Low: > 0.8

Unit: ratio

Task: DrillstringDesign
Description: Kick Tolerance (per hole section)
Short Name: Kick_Tol
Data Name: Bit_UCS
"Calculation: NA (already calculated), Exploration/Development"
Calculation Method: CalculateKick_Tol
PreCondition: Exporation
High: <= 50
Medium: <= 100
Low: > 100
Unit: bbl

Task: DrillstringDesign
Description: Kick Tolerance (per hole section)
Short Name: Kick_Tol
Data Name: Bit_UCS
"Calculation: NA (already calculated), Exploration/Development"
Calculation Method: CalculateKick_Tol
PreCondition: Development
High: <= 25
Medium: <= 50
Low: > 50
Unit: bbl

Task: Hydraulics
Description: Flow rate for hole cleaning (per depth)
Short Name: Q_Crit
"Data Name: Flow Rate, Critical Flow Rate"
Calculation: = Flow Rate/Critical Flow Rate
Calculation Method: CalculateQ_Crit
High: <= 1.0
Medium: <= 1.1
Low: > 1.1
Unit: Ratio

Task: Hydraulics
Description: Flow rate relative to pump capabilities(per depth)
Short Name: Q_Max
Data Name: Bit_UCS
Calculation: = Q/Qmax
Calculation Method: CalculateQ_Max
High: >= 1.0
Medium: >= 0.9

Low: < 0.9
Unit: Ratio

Task: Hydraulics
"Description: TFA size relative to minimum TFA (per bit run), 0.2301 = 3 of 10/32 inch, 0.3313 = 3 of 12/32inch"
Short Name: TFA_Low
Data Name: Bit_UCS
Calculation: TFA
Calculation Method: CalculateTFA_Low
High: <= 0.2301
Medium: <= 0.3313
Low: > 0.3313
Unit: inch

Task: Hydraulics
Description: Circulating pressure relative to rig and pump maximum pressure (per depth)
Short Name: P_Max
Data Name: Bit_UCS
Calculation: P_Max
Calculation Method: CalculateP_Max
High: >= 1.0
Medium: >= 0.9
Low: < 0.9
Unit: Ratio

Task: Hydraulics
Description: Loss potential where ECD is too high relative to Fracture Gradient (per depth)
Short Name: ECD_Frac
Data Name: Bit_UCS
Calculation: UpperBound-ECD
Calculation Method: CalculateECD_Frac
High: <= 0.0
Medium: <= 0.2
Low: > 0.2
Unit: ppg

Task: Hydraulics
Description: Loss potential where ECD is too high relative to Pore Pressure (per depth)
Short Name: ECD_Loss
Data Name: Bit_UCS
Calculation: = ECD – Pore Pressure
Calculation Method: CalculateECD_Loss
"PreCondition: Mud Type (HP-WBM, ND-WBM, D-WBM)"

High: >= 2500
Medium: >= 2000
Low: < 2000
Unit: psi

Task: Hydraulics
Description: Loss potential where ECD is too high relative to Pore Pressure (per depth)
Short Name: ECD_Loss
Data Name: Bit_UCS
Calculation: = ECD – Pore Pressure
Calculation Method: CalculateECD_Loss
"PreCondition: Mud Type (OBM, MOBM, SOBM)"
High: >= 2000
Medium: >= 1500
Low: < 1500
Unit: psi

Risk Assessment Algorithms 24

[0080] Recall that the 'Risk Assessment Logical Expressions' 22 will: (1) receive the 'Input Data 20a' including a 'plurality of Input Data calculation results' that has been generated by the 'Input Data 20a'; (2) determine whether each of the 'plurality of Input Data calculation results' represent a high risk, a medium risk, or a low risk; and (3) generate a plurality of Risk Values/plurality of Individual Risks in response thereto, where each of the plurality of Risk Values/plurality of Individual Risks represents a 'an Input Data calculation result' that has been 'ranked' as either a 'high risk', a 'medium risk', or a 'low risk'. For example, recall the following task:

Task: Hydraulics
Description: Loss potential where ECD is too high relative to Pore Pressure (per depth)
Short Name: ECD_Loss
Data Name: Bit_UCS
Calculation: = ECD – Pore Pressure
Calculation Method: CalculateECD_Loss
"PreCondition: Mud Type (OBM, MOBM, SOBM)"
High: >= 2000
Medium: >= 1500
Low: < 1500
Unit: psi

[0081] When the Calculation 'ECD- Pore Pressure' associated with the above referenced Hydraulics task is >= 2000, a 'high' rank is assigned to that calculation; but if the Calculation 'ECD - Pore Pressure' is >= 1500, a 'medium' rank is assigned to that calculation, but if the Calculation 'ECD – Pore Pressure' is < 1500, a 'low' rank is assigned to that calculation.

[0082] Therefore, the 'Risk Assessment Logical Expressions' 22 will rank each of the 'Input Data calculation results' as either a 'high risk' or a 'medium risk' or a 'low risk' thereby generating a 'plurality of ranked Risk Values', also known as a 'plurality of ranked Individual Risks'. In response to the 'plurality of ranked Individual Risks' received from the Logical Expressions 22, the 'Risk Assessment Logical Algorithms' 24 will then assign a 'value' and a 'color' to each of the plurality of ranked Individual Risks received from the Logical Expressions 22, where the 'value' and the 'color' depends upon the particular ranking (i.e., the 'high risk' rank, or the 'medium risk' rank, or the 'low risk' rank) that is associated with each of the plurality of ranked Individual Risks. The 'value' and the 'color' is assigned, by the 'Risk Assessment Algorithms' 24, to each of the plurality of Individual Risks received from the Logical Expressions 22 in the following manner:

<u>Risk Calculation #1 - Individual Risk Calculation:</u>

[0083] Referring to the 'Risk Assessment Output Data' 18b1 set forth above, there are fifty-four (54) 'Individual Risks' currently specified. For an 'Individual Risk':

a High risk = 90,
a Medium risk = 70, and
a Low risk = 10

High risk color code = Red
Medium risk color code = Yellow
Low risk color code = Green

[0084] If the 'Risk Assessment Logical Expressions' 22 assigns a 'high risk' rank to a particular 'Input Data calculation result', the 'Risk Assessment Algorithms' 24 will then assign a value '90' to that 'Input Data calculation result' and a color 'red' to that 'Input Data calculation result'.

[0085] If the 'Risk Assessment Logical Expressions' 22 assigns a 'medium risk' rank to a particular 'Input Data calculation result', the 'Risk Assessment Algorithms' 24 will then assign a value '70' to that 'Input Data calculation result' and a color 'yellow' to that 'Input Data calculation result'.

[0086] If the 'Risk Assessment Logical Expressions' 22 assigns a 'low risk' rank to a particular 'Input Data calculation result', the 'Risk Assessment Algorithms' 24 will then assign a value '10' to that 'Input Data calculation result' and a color 'green' to that 'Input Data calculation result'.

[0087] Therefore, in response to the 'Ranked Individual Risks' from the Logical Expressions 22, the Risk Assessment Algorithms 24 will assign to each of the 'Ranked Individual Risks' a value of 90 and a color 'red' for a high risk, a value of 70 and a color 'yellow' for the medium risk, and a value of 10 and a color 'green' for the low risk. However, in addition, in response to the 'Ranked Individual Risks' from the Logical Expressions 22, the Risk Assessment Algorithms 24 will also generate a plurality of ranked 'Risk Categories' and a plurality of ranked 'Subcategory Risks'

[0088] Referring to the 'Risk Assessment Output Data' 18b1 set forth above, the 'Risk Assessment Output Data' 18b1 includes: (1) eight 'Risk Categories', (2) four 'Subcategory Risks', and (3) fifty-four (54) 'Individual Risks' [that is, 54 individual risks plus 2 'gains' plus 2 'losses' plus 2 'stuck' plus 2 'mechanical' plus 1 'total' = 63 risks].

[0089] The eight 'Risk Categories' include the following: (1) an Individual Risk, (2) an Average Individual Risk, (3) a Risk Subcategory (or Subcategory Risk), (4) an Average

Subcategory Risk, (5) a Risk Total (or Total Risk), (6) an Average Total Risk, (7) a potential Risk for each design task, and (8) an Actual Risk for each design task.

[0090] Recalling that the 'Risk Assessment Algorithms' 24 have already established and generated the above referenced 'Risk Category (1)' [i.e., the plurality of ranked Individual Risks'] by assigning a value of 90 and a color 'red' to a high risk 'Input Data calculation result', a value of 70 and a color 'yellow' to a medium risk 'Input Data calculation result', and a value of 10 and a color 'green' to a low risk 'Input Data calculation result', the 'Risk Assessment Algorithms' 24 will now calculate and establish and generate the above referenced 'Risk Categories (2) through (8)' in response to the plurality of Risk Values/plurality of Individual Risks received from the 'Risk Assessment Logical Expressions' 22 in the following manner:

<u>Risk Calculation #2 - Average Individual Risk:</u>

[0091] The average of all of the 'Risk Values' is calculated as follows:

$$Average\ individual\ risk = \frac{\sum_i^n Riskvalue_i}{n}$$

[0092] In order to determine the 'Average Individual Risk', sum the above referenced 'Risk Values' and then divide by the number of such 'Risk Values', where i = number of sample points. The value for the 'Average Individual Risk' is displayed at the bottom of the colored individual risk track.

<u>Risk Calculation #3 - Risk subcategory</u>

[0093] Referring to the 'Risk Assessment Output Data' 18b1 set forth above, the following 'Subcategory Risks' are defined: (a) gains, (b) losses, (c) stuck and (d) mechanical, where a 'Subcategory Risk' (or 'Risk Subcategory') is defined as follows:

$$Risk\ Subcategory = \frac{\sum_j^n (Riskvalue_j\ x\ severity_j\ x\ N_j)}{\sum_j (severity_j x\ N_j)}$$

j = number of individual risks,

$0 \le \text{Severity} \le 5$, and

N_j = either 1 or 0 depending on whether the Risk Value_j contributes to the sub category

Severity_j = from the risk matrix catalog.

Red risk display for $Risk\ Subcategory \ge 40$

Yellow risk display for $20 \le Risk\ \ Subcategor\, y < 40$

Green risk display for $Risk\ Subcategory < 20$

Risk Calculation #4 - Average subcategory risk:

$$Average\ subcategory\, risk = \frac{\sum_i^n (Risk\ Subcategory_i\ x\ risk\, multiplier_i)}{\sum_1^n risk\, multiplier_i}$$

n = number of sample points.

The value for the average subcategory risk is displayed at the bottom of the colored subcategory risk track.

Risk Multiplier = 3 for $Risk\ Subcategory \ge 40$,

Risk Multiplier = 2 for $20 \le Risk\ \ Subcategor\, y < 40$

Risk Multiplier = 1 for $Risk\ Subcategory < 20$

Risk Calculation #5 - Total Risk

The total risk calculation is based on the following categories: (a) gains, (b) losses, (c) stuck, and (d) mechanical.

$$Risk\ Total = \frac{\sum_1^4 Risk\ subcategory_k}{4}$$ where k = number of subcategories

Red risk display for $Risk\ total \geq 40$

Yellow risk display for $20 \leq Risk\ Total < 40$

Green risk display for $Risk\ Total < 20$

Risk Calculation #6 – Average Total Risk

$$Average\ total\ risk = \frac{\sum_i^n (Risk\ Subcategory_i\ x\ risk\ multiplier_i)}{\sum_1^n risk\ multiplier_i}$$

n = number of sample points.

Risk Multiplier = 3 for $Risk\ Subcategory \geq 40$,

Risk Multiplier = 2 for $20 \leq Risk\ Subcategory < 40$

Risk Multiplier = 1 for $Risk\ Subcategory < 20$

The value for the average total risk is displayed at the bottom of the colored total risk track.

Risk calculation #7 - Risks per design task:

The following 14 design tasks have been defined: Scenario, Trajectory, Mechanical Earth Model, Rig, Wellbore stability, Mud weight and casing points, Wellbore Sizes, Casing,

Cement, Mud, Bit, Drillstring, Hydraulics, and Time design. There are currently 54 individual risks specified.

Risk calculation #7A - Potential maximum risk per design task

$$Potential\ Risk_k = \frac{\sum_{j=1}^{55} (90\ x\ Severity_{k,j}\ x\ N_{k,j})}{\sum_{j=1}^{55} (Severity_{k,j} x\ N_{k,j})}$$

k = index of design tasks, there are 14 design tasks,

N_j = either 0 or 1 depending on whether the Risk $Value_j$ contributes to the design task.

$0 \leq$ Severity ≤ 5

Risk calculation #7B - Actual risk per design task

$$Actual\ Risk_k = \frac{\sum_{j=1}^{55} (Average\ Individual\ Risk_j\ x\ Severity_{,j}\ x\ N_{k,j})}{\sum_{j=1}^{55} (Severity_j x\ N_{k,j})}$$

k = index of design tasks, there are 14 design tasks

$N_{k,j} \in [0,\ldots,M]$

$0 \leq \text{Severity}_j \leq 5$

The 'Severity' in the above equations are defined as follows:

Risk	Severity
H2S_CO2	2.67
Hydrates	3.33
Well_WD	3.67
DLS	3
TORT	3
Well_MD	4.33
INC	3
Hor_Disp	4.67

DDI	4.33
PP_High	4.33
PP_Low	2.67
RockHard	2
RockSoft	1.33
TempHigh	3
Rig_WD	5
Rig_MD	5
SS_BOP	3.67
MW_Kick	4
MW_Loss	3
MW_Frac	3.33
MWW	3.33
WBS	3
WBSW	3.33
HSLength	3
Hole_Big	2
Hole_Sm	2.67
Hole_Csg	2.67
Csg_Csg	2.33
Csg_Bit	1.67
Csg_DF	4
Csg_Wt	3
Csg_MOP	2.67
Csg_Wear	1.33
Csg_Count	4.33
TOC_Low	1.67
Cmt_Kick	3.33
Cmt_Loss	2.33
Cmt_Frac	3.33
Bit_Wk	2.33
Bit_WkXS	2.33
Bit_Ftg	2.33
Bit_Hrs	2
Bit_Krev	2
Bit_ROP	2
Bit_UCS	3
DS_MOP	3.67
DS_Part	3
Kick_Tol	4.33
Q_Crit	2.67
Q_Max	3.33
Cutting	3.33
P_Max	4
TFA_Low	1.33
ECD_Frac	4
ECD_Loss	3.33

[0094] Refer now to figure 11 which will be used during the following functional description of the operation of the present invention.

[0095] A functional description of the operation of the 'Automatic Well Planning Risk Assessment Software' 18c1 will be set forth in the following paragraphs with reference to figures 1 through 11 of the drawings.

[0096] The Input Data 20a shown in figure 9A will be introduced as 'input data' to the Computer System 18 of figure 9A. The Processor 18a will execute the Automatic Well Planning Risk Assessment Software 18c1, while using the Input Data 20a, and, responsive thereto, the Processor 18a will generate the Risk Assessment Output Data 18b1, the Risk Assessment Output Data 18b1 being recorded or displayed on the Recorder or Display Device 18b in the manner illustrated in figure 9B. The Risk Assessment Output Data 18b1 includes the 'Risk Categories', the 'Subcategory Risks', and the 'Individual Risks'. When the Automatic Well Planning Risk Assessment Software 18c1 is executed by the Processor 18a of figure 9A, referring to figures 10 and 11, the Input Data 20a (and the Risk Assessment Constants 26 and the Risk Assessment Catalogs 28) are collectively provided as 'input data' to the Risk Assessment Logical Expressions 22. Recall that the Input Data 20a includes a 'plurality of Input Data Calculation results'. As a result, as denoted by element numeral 32 in figure 11, the 'plurality of Input Data Calculation results' associated with the Input Data 20a will be provided directly to the Logical Expressions block 22 in figure 11. During that execution of the Logical Expressions 22 by the Processor 18a, each of the 'plurality of Input Data Calculation results' from the Input Data 20a will be compared with each of the 'logical expressions' in the Risk Assessment Logical Expressions block 22 in figure 11. When a match is found between an 'Input Data Calculation result' from the Input Data 20a and an 'expression' in the Logical Expressions block 22, a 'Risk Value' or 'Individual Risk' 34 will be generated (by the Processor 18a) from the Logical Expressions block 22 in figure 11. As a result, since a 'plurality of Input Data Calculation results' 32 from the Input Data 20a have been compared with a 'plurality of

expressions' in the Logical Expressions' block 22 in figure 11, the Logical Expressions block 22 will generate a plurality of Risk Values/plurality of Individual Risks 34 in figure 11, where each of the plurality of Risk Values/plurality of Individual Risks on line 34 in figure 11 that are generated by the Logical Expressions block 22 will represent an 'Input Data Calculation result' from the Input Data 20a that has been ranked as either a 'High Risk', or a 'Medium Risk', or a 'Low Risk' by the Logical Expressions block 22. Therefore, a 'Risk Value' or 'Individual Risk' is defined as an 'Input Data Calculation result' from the Input Data 20a that has been matched with one of the 'expressions' in the Logical Expressions 22 and ranked, by the Logical Expressions block 22, as either a 'High Risk', or a 'Medium Risk', or a 'Low Risk'. For example, consider the following 'expression' in the Logical Expressions' 22:

Task: MudWindow
Description: Hole section length (per hole section)
Short Name: HSLength
Data Name:
Calculation: = HoleEnd - HoleStart
Calculation Method: CalculateHSLength
High: >= 8000
Medium: >= 7001
Low: < 7001

[0097] The 'Hole End – HoleStart' calculation is an 'Input Data Calculation result' from the Input Data 20a. The Processor 18a will find a match between the 'Hole End – HoleStart Input Data Calculation result' originating from the Input Data 20a and the above identified 'expression' in the Logical Expressions 22. As a result, the Logical Expressions block 22 will 'rank' the 'Hole End – HoleStart Input Data Calculation result' as either a 'High Risk', or a 'Medium Risk', or a 'Low Risk' depending upon the value of the 'Hole End – HoleStart Input Data Calculation result'.

[0098] When the 'Risk Assessment Logical Expressions' 22 ranks the 'Input Data calculation result' as either a 'high risk' or a 'medium risk' or a 'low risk' thereby generating a plurality of ranked Risk Values/plurality of ranked Individual Risks, the

'Risk Assessment Logical Algorithms' 24 will then assign a 'value' and a 'color' to that ranked 'Risk Value' or ranked 'Individual Risk', where the 'value' and the 'color' depends upon the particular ranking (i.e., the 'high risk' rank, or the 'medium risk' rank, or the 'low risk' rank) that is associated with that 'Risk Value' or 'Individual Risk'. The 'value' and the 'color' is assigned, by the 'Risk Assessment Logical Algorithms' 24, to the ranked 'Risk Values' or ranked 'Individual Risks' in the following manner:

a High risk = 90,
a Medium risk = 70, and
a Low risk = 10

High risk color code = Red
Medium risk color code = Yellow
Low risk color code = Green

[0099] If the 'Risk Assessment Logical Expressions' 22 assigns a 'high risk' rank to the 'Input Data calculation result' thereby generating a ranked 'Individual Risk', the 'Risk Assessment Logical Algorithms' 24 assigns a value '90' to that ranked 'Risk Value' or ranked 'Individual Risk' and a color 'red' to that ranked 'Risk Value' or that ranked 'Individual Risk'. If the 'Risk Assessment Logical Expressions' 22 assigns a 'medium risk' rank to the 'Input Data calculation result' thereby generating a ranked 'Individual Risk', the 'Risk Assessment Logical Algorithms' 24 assigns a value '70' to that ranked 'Risk Value' or ranked 'Individual Risk' and a color 'yellow' to that ranked 'Risk Value' or that ranked 'Individual Risk'. If the 'Risk Assessment Logical Expressions' 22 assigns a 'low risk' rank to the 'Input Data calculation result' thereby generating a ranked 'Individual Risk', the 'Risk Assessment Logical Algorithms' 24 assigns a value '10' to that ranked 'Risk Value' or ranked 'Individual Risk' and a color 'green' to that ranked 'Risk Value' or that ranked 'Individual Risk'.

[00100] Therefore, in figure 11, a plurality of ranked Individual Risks (or ranked Risk Values) is generated, along line 34, by the Logical Expressions block 22, the plurality of ranked Individual Risks (which forms a part of the 'Risk Assessment Output Data' 18b1) being provided directly to the 'Risk Assessment Algorithms' block 24. The 'Risk

Assessment Algorithms' block 24 will receive the plurality of ranked Individual Risks' from line 34 and, responsive thereto, the 'Risk Assessment Algorithms' 24 will: (1) generate the 'Ranked Individual Risks' including the 'values' and 'colors' associated therewith in the manner described above, and, in addition, (2) calculate and generate the 'Ranked Risk Categories' 40 and the 'Ranked Subcategory Risks' 40 associated with the 'Risk Assessment Output Data' 18b1. The 'Ranked Risk Categories' 40 and the 'Ranked Subcategory Risks' 40 and the 'Ranked Individual Risks' 40 can now be recorded or displayed on the Recorder or Display device 18b. Recall that the 'Ranked Risk Categories' 40 include: an Average Individual Risk, an Average Subcategory Risk, a Risk Total (or Total Risk), an Average Total Risk, a potential Risk for each design task, and an Actual Risk for each design task. Recall that the 'Ranked Subcategory Risks' 40 include: a Risk Subcategory (or Subcategory Risk).

[00101] As a result, recalling that the 'Risk Assessment Output Data' 18b1 includes 'one or more Risk Categories' and 'one or more Subcategory Risks' and 'one or more Individual Risks', the 'Risk Assessment Output Data' 18b1, which includes the Risk Categories 40 and the Subcategory Risks 40 and the Individual Risks 40, can now be recorded or displayed on the Recorder or Display Device 18b of the Computer System 18 shown in figure 9A.

[00102] As noted earlier, the 'Risk Assessment Algorithms' 24 will receive the 'Ranked Individual Risks' from the Logical Expressions 22 along line 34 in figure 11; and, responsive thereto, the 'Risk Assessment Algorithms' 24 will (1) assign the 'values' and the 'colors' to the 'Ranked Individual Risks' in the manner described above, and, in addition, (2) calculate and generate the 'one or more Risk Categories' 40 and the 'one or more Subcategory Risks' 40 by using the following equations (set forth above).

[00103] The average Individual Risk is calculated from the 'Risk Values' as follows:

$$Average\ individual\ risk = \frac{\sum_i^n Riskvalue_i}{n}$$

[00104] The Subcategory Risk, or Risk Subcategory, is calculated from the 'Risk Values' and the 'Severity', as defined above, as follows:

$$Risk\ Subcategory = \frac{\sum_j^n (Riskvalue_j\ x\ severity_j\ x\ N_j)}{\sum_j (severity_j x\ N_j)}$$

[00105] The Average Subcategory Risk is calculated from the Risk Subcategory in the following manner, as follows:

$$Average\ subcategory\, risk = \frac{\sum_i^n (Risk\ Subcategory_i\ x\ risk\, multiplier_i)}{\sum_1^n risk\, multiplier_i}$$

[00106] The Risk Total is calculated from the Risk Subcategory in the following manner, as follows:

$$Risk\ Total = \frac{\sum_1^4 Risk\ \ subcategory_k}{4}$$

[00107] The Average Total Risk is calculated from the Risk Subcategory in the following manner, as follows:

$$Average\ total\, risk = \frac{\sum_i^n (Risk\ Subcategory_i\ x\ risk\, multiplier_i)}{\sum_1^n risk\, multiplier_i}$$

[00108] The Potential Risk is calculated from the Severity, as defined above, as follow:

$$Potential\ Risk_k = \frac{\sum_{j=1}^{55}(90\ x\ Severity_{k,j}\ x\ N_{k,j})}{\sum_{j=1}^{55}(Severity_{k,j} x\ N_{k,j})}$$

[00109] The Actual Risk is calculated from the Average Individual Risk and the Severity (defined above) as follows:

$$Actual\ Risk_k = \frac{\sum_{j=1}^{55}(Average\ Individual\ Risk_j\ x\ Severity_{,j}\ x\ N_{k,j})}{\sum_{j=1}^{55}(Severity_j x\ N_{k,j})}$$

[00110] Recall that the Logical Expressions block 22 will generate a 'plurality of Risk Values/Ranked Individual Risks' along line 34 in figure 11, where each of the 'plurality of Risk Values/Ranked Individual Risks' generated along line 34 represents a received 'Input Data Calculation result' from the Input Data 20a that has been 'ranked' as either a 'High Risk', or a 'Medium Risk', or a 'Low Risk' by the Logical Expressions 22. A 'High Risk' will be assigned a 'Red' color, and a 'Medium Risk' will be assigned a 'Yellow' color, and a 'Low Risk' will be assigned a 'Green' color. Therefore, noting the word 'rank' in the following, the Logical Expressions block 22 will generate (along line 34 in figure 11) a 'plurality of ranked Risk Values/ranked Individual Risks'.

[00111] In addition, in figure 11, recall that the 'Risk Assessment Algorithms' block 24 will receive (from line 34) the 'plurality of ranked Risk Values/ranked Individual Risks' from the Logical Expressions block 22. In response thereto, noting the word 'rank' in the following, the 'Risk Assessment Algorithms' block 24 will generate: (1) the 'one or more Individual Risks having 'values' and 'colors' assigned thereto, (2) the 'one or more ranked Risk Categories' 40, and (3) the 'one or more ranked Subcategory Risks' 40. Since the 'Risk Categories' and the 'Subcategory Risks' are each 'ranked', a 'High Risk' (associated with a Risk Category 40 or a Subcategory Risk 40) will be assigned a 'Red' color, and a 'Medium Risk' will be assigned a 'Yellow' color, and a 'Low Risk' will be assigned a 'Green' color. In view of the above 'rankings' and the colors associated

therewith, the 'Risk Assessment Output Data' 18b1, including the 'ranked' Risk Categories 40 and the 'ranked' Subcategory Risks 40 and the 'ranked' Individual Risks 38, will be recorded or displayed on the Recorder or Display Device 18b of the Computer System 18 shown in figure 9A in the manner illustrated in figure 9B.

<u>Automatic Well Planning Software System – Bit Selection sub-task 14a</u>

[00112] In figure 8, the Bit Selection sub-task 14a is illustrated.

[00113] The selection of Drill bits is a manual subjective process based heavily on personal, previous experiences. The experience of the individual recommending or selecting the drill bits can have a large impact on the drilling performance for the better or for the worse. The fact that bit selection is done primarily based on personal experiences and uses little information of the actual rock to be drilled makes it very easy to choose the incorrect bit for the application.

[00114] The Bit Selection sub-task 14a utilizes an 'Automatic Well Planning Bit Selection software', in accordance with the present invention, to automatically generate the required drill bits to drill the specified hole sizes through the specified hole section at unspecified intervals of earth. The 'Automatic Well Planning Bit Selection software' of the present invention includes a piece of software (called an 'algorithm') that is adapted for automatically selecting the required sequence of drill bits to drill each hole section (defined by a top/bottom depth interval and diameter) in the well. It uses statistical processing of historical bit performance data and several specific Key Performance Indicators (KPI) to match the earth properties and rock strength data to the appropriate bit while optimizing the aggregate time and cost to drill each hole section. It determines the bit life and corresponding depths to pull and replace a bit based on proprietary algorithms, statistics, logic, and risk factors.

[00115] Referring to figure 12, a Computer System 42 is illustrated. The Computer System 42 includes a Processor 42a connected to a system bus, a Recorder or Display

Device 42b connected to the system bus, and a Memory or Program Storage Device 42c connected to the system bus. The Recorder or Display Device 42b is adapted to display 'Bit Selection Output Data' 42b1. The Memory or Program Storage Device 42c is adapted to store an 'Automatic Well Planning Bit selection Software' 42c1. The 'Automatic Well Planning Bit selection Software' 42c1 is originally stored on another 'program storage device', such as a hard disk; however, the hard disk was inserted into the Computer System 42 and the 'Automatic Well Planning Bit selection Software' 42c1 was loaded from the hard disk into the Memory or Program Storage Device 42c of the Computer System 42 of figure 12. In addition, a Storage Medium 44 containing a plurality of 'Input Data' 44a is adapted to be connected to the system bus of the Computer System 42, the 'Input Data' 44a being accessible to the Processor 42a of the Computer System 42 when the Storage Medium 44 is connected to the system bus of the Computer System 42. In operation, the Processor 42a of the Computer System 42 will execute the Automatic Well Planning Bit selection Software 42c1 stored in the Memory or Program Storage Device 42c of the Computer System 42 while, simultaneously, using the 'Input Data' 44a stored in the Storage Medium 44 during that execution. When the Processor 42a completes the execution of the Automatic Well Planning Bit selection Software 42c1 stored in the Memory or Program Storage Device 42c (while using the 'Input Data' 44a), the Recorder or Display Device 42b will record or display the 'Bit selection Output Data' 42b1, as shown in figure 12. For example the 'Bit selection Output Data' 42b1 can be displayed on a display screen of the Computer System 42, or the 'Bit selection Output Data' 42b1 can be recorded on a printout which is generated by the Computer System 42. The 'Input Data' 44a and the 'Bit Selection Output Data' 42b1 will be discussed and specifically identified in the following paragraphs of this specification. The 'Automatic Well Planning Bit Selection software' 42c1 will also be discussed in the following paragraphs of this specification. The Computer System 42 of figure 12 may be a personal computer (PC). The Memory or Program Storage Device 42c is a computer readable medium or a program storage device which is readable by a machine, such as the processor 42a. The processor 42a may be, for example, a microprocessor, a microcontroller, or a mainframe or workstation processor. The Memory or Program

Storage Device 42c, which stores the 'Automatic Well Planning Bit selection Software' 42c1, may be, for example, a hard disk, ROM, CD-ROM, DRAM, or other RAM, flash memory, magnetic storage, optical storage, registers, or other volatile and/or non-volatile memory.

[00116] Referring to figure 13, a detailed construction of the 'Automatic Well Planning Bit selection Software' 42c1 of figure 12 is illustrated. In figure 13, the 'Automatic Well Planning Bit selection Software' 42c1 includes a first block which stores the Input Data 44a, a second block 46 which stores a plurality of Bit selection Logical Expressions 46; a third block 48 which stores a plurality of Bit selection Algorithms 48, a fourth block 50 which stores a plurality of Bit selection Constants 50, and a fifth block 52 which stores a plurality of Bit selection Catalogs 52. The Bit selection Constants 50 include values which are used as input for the Bit selection Algorithms 48 and the Bit selection Logical Expressions 46. The Bit selection Catalogs 52 include look-up values which are used as input by the Bit selection Algorithms 48 and the Bit selection Logical Expressions 46. The 'Input Data' 44a includes values which are used as input for the Bit selection Algorithms 48 and the Bit selection Logical Expressions 46. The 'Bit selection Output Data' 42b1 includes values which are computed by the Bit selection Algorithms 48 and which result from the Bit selection Logical Expressions 46. In operation, referring to figures 12 and 13, the Processor 42a of the Computer System 42 of figure 12 executes the Automatic Well Planning Bit selection Software 42c1 by executing the Bit selection Logical Expressions 46 and the Bit selection Algorithms 48 of the Bit selection Software 42c1 while, simultaneously, using the 'Input Data' 44a, the Bit selection Constants 50, and the values stored in the Bit selection Catalogs 52 as 'input data' for the Bit selection Logical Expressions 46 and the Bit selection Algorithms 48 during that execution. When that execution by the Processor 42a of the Bit selection Logical Expressions 46 and the Bit selection Algorithms 48 (while using the 'Input Data' 44a, Constants 50, and Catalogs 52) is completed, the 'Bit selection Output Data' 42b1 will be generated as a 'result'. The 'Bit selection Output Data' 42b1 is recorded or displayed on the Recorder or Display Device 42b of the Computer System 42 of figure 12. In addition, that 'Bit selection

Output Data' 42b1 can be manually input, by an operator, to the Bit selection Logical Expressions block 46 and the Bit selection Algorithms block 48 via a 'Manual Input' block 54 shown in figure 13.

Input Data 44a

[00117] The following paragraphs will set forth the 'Input Data' 44a which is used by the 'Bit Selection Logical Expressions' 46 and the 'Bit Selection Algorithms' 48. Values of the Input Data 44a that are used as input for the Bit Selection Algorithms 48 and the Bit Selection Logical Expressions 46 include the following:

(1) Measured Depth
(2) Unconfined Compressive Strength
(3) Casing Point Depth
(4) Hole Size
(5) Conductor
(6) Casing Type Name
(7) Casing Point
(8) Day Rate Rig
(9) Spread Rate Rig
(10) Hole Section Name

Bit selection Constants 50

[00118] The 'Bit Selection Constants' 50 are used by the 'Bit selection Logical Expressions' 46 and the 'Bit selection Algorithms' 48. The values of the 'Bit Selection Constants 50 that are used as input data for Bit selection Algorithms 48 and the Bit selection Logical Expressions 46 include the following: Trip Speed

Bit selection Catalogs 52

[00119] The 'Bit selection Catalogs' 52 are used by the 'Bit selection Logical Expressions' 46 and the 'Bit selection Algorithms' 48. The values of the Catalogs 52 that

are used as input data for Bit selection Algorithms 48 and the Bit selection Logical Expressions 46 include the following: Bit Catalog

Bit selection Output Data 42b1

[00120] The 'Bit selection Output Data' 42b1 is generated by the 'Bit selection Algorithms' 48. The 'Bit selection Output Data' 42b1, that is generated by the 'Bit selection Algorithms' 48, includes the following types of output data:

(1) Measured Depth
(2) Cumulative Unconfined Compressive Strength (UCS)
(3) Cumulative Excess UCS
(4) Bit Size
(5) Bit Type
(6) Start Depth
(7) End Depth
(8) Hole Section Begin Depth
(9) Average UCS of rock in section
(10) Maximum UCS of bit
(11) BitAverage UCS of rock in section
(12) Footage
(13) Statistical Drilled Footage for the bit
(14) Ratio of footage drilled compared to statistical footage
(15) Statistical Bit Hours
(16) On Bottom Hours
(17) Rate of Penetration (ROP)
(18) Statistical Bit Rate of Penetration (ROP)
(19) Mechanical drilling energy (UCS integrated over distance drilled by the bit)
(20) Weight On Bit
(21) Revolutions per Minute (RPM)
(22) Statistical Bit RPM
(23) Calculated Total Bit Revolutions
(24) Time to Trip
(25) Cumulative Excess as a ration to the Cumulative UCS
(26) Bit Cost
(27) Hole Section Name

Bit selection Logical Expressions 46

[00121] The following paragraphs will set forth the 'Bit selection Logical Expressions' 46. The 'Bit selection Logical Expressions' 46 will: (1) receive the 'Input Data 44a', including a 'plurality of Input Data calculation results' that has been generated by the 'Input Data 44a'; and (2) evaluate the 'Input Data calculation results' during the processing of the 'Input Data'.

[00122] The Bit Selection Logical Expressions 46, which evaluate the processing of the Input Data 44a, include the following:

(1) Verify the hole size and filter out the bit sizes that do not match the hole size.
(2) Check if the bit is not drilling beyond the casing point.
(3) Check the cumulative mechanical drilling energy for the bit run and compare it with the statistical mechanical drilling energy for that bit, and assign the proper risk to the bit run.
(4) Check the cumulative bit revolutions and compare it with the statistical bit revolutions for that bit type and assign the proper risk to the bit run.
(5) Verify that the encountered rock strength is not outside the range of rock strengths that is optimum for the selected bit type.
(6) Extend footage by 25% in case the casing point could be reached by the last selected bit.

Bit Selection Algorithms 48

[00123] The following paragraphs will set forth the 'Bit Selection Algorithms' 48. The 'Bit Selection Algorithms' 48 will receive the output from the 'Bit Selection Logical Expressions' 46 and process that 'output from the Bit Selection Logical Expressions 46' in the following manner:

(1) Read variables and constants

(2) Read catalogs

(3) Build cumulative rock strength curve from casing point to casing point.

$$CumUCS = \int_{start}^{end} (UCS) d\ ft$$

(4) Determine the required hole size

(5) Find the bit candidates that match the closest unconfined compressive strength of the rock to drill.

(6) Determine the end depth of the bit by comparing the historical drilling energy with the cumulative rock strength curve for all bit candidates.

(7) Calculate the cost per foot for each bit candidate taking into accounts the rig rate, trip speed and drilling rate of penetration.

$$TOT\ Cost = (RIG\ RATE + SPREAD\ RATE)(T\_TripIn + \frac{footage}{ROP} + T\_Trip) + Bit\ Cost$$

(8) Evaluate which bit candidate is most economic.

(9) Calculate the remaining cumulative rock strength to casing point.

(10) Repeat step 5 to 9 until the end of the hole section

(11) Build cumulative UCS

(12) Select bits – display bit performance and operating parameters

(13) Remove sub-optimum bits

(14) Find most economic bit based on cost per foot

[00124] Refer now to figures 14A and 14B which will be used during the following functional description of the operation of the present invention.

[00125] A functional description of the operation of the 'Automatic Well Planning Bit Selection Software' 42c1 will be set forth in the following paragraphs with reference to figures 1 through 14B of the drawings.

[00126] Recall that the selection of Drill bits is a manual subjective process based heavily on personal, previous experiences. The experience of the individual

recommending or selecting the drill bits can have a large impact on the drilling performance for the better or for the worse. The fact that bit selection is done primarily based on personal experiences and uses little information of the actual rock to be drilled makes it very easy to choose the incorrect bit for the application. Recall that the Bit Selection sub-task 14a utilizes an 'Automatic Well Planning Bit Selection software' 42c1, in accordance with the present invention, to automatically generate the required roller cone drill bits or fixed cutter drill bits (e.g., PDC bits) to drill the specified hole sizes through the specified hole section at unspecified intervals of earth. The 'Automatic Well Planning Bit Selection software' 42c1 of the present invention include the 'Bit Selection Logical Expressions' 46 and the 'Bit Selection Algorithms' 48 that are adapted for automatically selecting the required sequence of drill bits to drill each hole section (defined by a top/bottom depth interval and diameter) in the well. The 'Automatic Well Planning Bit Selection software' 42c1 uses statistical processing of historical bit performance data and several specific Key Performance Indicators (KPI) to match the earth properties and rock strength data to the appropriate bit while optimizing the aggregate time and cost to drill each hole section. It determines the bit life and corresponding depths to pull and replace a bit based on proprietary algorithms, statistics, logic, and risk factors.

[00127] In figure 14A, the Input Data 44a represents a set of Earth formation characteristics, where the Earth formation characteristics are comprised of data representing characteristics of a particular Earth formation 'To Be Drilled'. The Logical Expressions and Algorithms 46/48 are comprised of Historical Data 60, where the Historical Data 60 can be viewed as a table consisting of two columns: a first column 60a including 'historical Earth formation characteristics', and a second column 60b including 'sequences of drill bits used corresponding to the historical Earth formation characteristics'. The Recorder or Display device 42b will record or display 'Bit Selection Output Data' 42b, where the 'Bit Selection Output Data' 42b is comprised of the 'Selected Sequence of Drill Bits, and other associated data'. In operation, referring to figure 14A, the Input Data 44a represents a set of Earth formation characteristics

associated with an Earth formation 'To Be Drilled'. The 'Earth formation characteristics (associated with a section of Earth Formation 'to be drilled') corresponding to the Input Data 44a' is compared with each 'characteristic in column 60a associated with the Historical Data 60' of the Logical Expressions and Algorithms 46/48. When a match (or a substantial match) is found between the 'Earth formation characteristics (associated with a section of Earth Formation 'to be drilled') corresponding to the Input Data 44a' and a 'characteristic in column 60a associated with the Historical Data 60', a 'Sequence of Drill Bits' (called a 'selected sequence of drill bits') corresponding to that 'characteristic in column 60a associated with the Historical Data 60' is generated as an output from the Logical Expressions and Algorithms block 46/48 in figure 14A. The aforementioned 'selected sequence of drill bits along with other data associated with the selected sequence of drill bits' is generated as an 'output' by the Recorder or Display device 42b of the Computer System 42 in figure 12. See figure 15 for an example of that 'output'. The 'output' can be a 'display' (as illustrated in figure 15) that is displayed on a computer display screen, or it can be an 'output record' printed by the Recorder or Display device 42b.

[00128] The functions discussed above with reference to figure 14A, pertaining to the manner by which the 'Logical Expressions and Algorithms' 46/48 will generate the 'Bit Selection Output Data' 42b1 in response to the 'Input Data' 44a, will be discussed in greater detail below with reference to figure 14B.

[00129] In figure 14B, recall that the Input Data 44a represents a set of 'Earth formation characteristics', where the 'Earth formation characteristics' are comprised of data representing characteristics of a particular Earth formation 'To Be Drilled'. As a result, the Input Data 44a is comprised of the following specific data: Measured Depth, Unconfined Compressive Strength, Casing Point Depth, Hole Size, Conductor, Casing Type Name, Casing Point, Day Rate Rig, Spread Rate Rig, and Hole Section Name.

[00130] In figure 14B, recall that the Logical Expressions 46 and Algorithms 48 will respond to the Input Data 44a by generating a set of 'Bit Selection Output Data' 42b1, where the 'Bit Selection Output Data' 42b1 represents the aforementioned 'selected drill bit along with other data associated with the selected drill bit'. As a result, the 'Bit Selection Output Data' 42b1 is comprised of the following specific data: Measured Depth, Cumulative Unconfined Compressive Strength (UCS), Cumulative Excess UCS, Bit Size, Bit Type, Start Depth, End Depth, Hole Section Begin Depth, Average UCS of rock in section, Maximum UCS of bit, Bit Average UCS of rock in section, Footage, Statistical Drilled Footage for the bit, Ratio of footage drilled compared to statistical footage, Statistical Bit Hours, On Bottom Hours, Rate of Penetration (ROP), Statistical Bit Rate of Penetration (ROP), Mechanical drilling energy (UCS integrated over distance drilled by the bit), Weight On Bit, Revolutions per Minute (RPM), Statistical Bit RPM, Calculated Total Bit Revolutions, Time to Trip, Cumulative Excess as a ration to the Cumulative UCS, Bit Cost, and Hole Section Name.

[00131] In order to generate the 'Bit Selection Output Data' 42b1 in response to the 'Input Data' 44a, the Logical Expressions 46 and the Algorithms 48 must perform the following functions, which are set forth in the following paragraphs.

[00132] The Bit Selection Logical Expressions 46 will perform the following functions. The Bit Selection Logical Expressions 46 will: (1) Verify the hole size and filter out the bit sizes that do not match the hole size, (2) Check if the bit is not drilling beyond the casing point, (3) Check the cumulative mechanical drilling energy for the bit run and compare it with the statistical mechanical drilling energy for that bit, and assign the proper risk to the bit run, (4) Check the cumulative bit revolutions and compare it with the statistical bit revolutions for that bit type and assign the proper risk to the bit run, (5) Verify that the encountered rock strength is not outside the range of rock strengths that is optimum for the selected bit type, and (6) Extend footage by 25% in case the casing point could be reached by the last selected bit.

[00133] The Bit Selection Algorithms 48 will perform the following functions. The Bit Selection Algorithms 48 will: (1) Read variables and constants, (2) Read catalogs, (3) Build cumulative rock strength curve from casing point to casing point, using the following equation:

$$CumUCS = \int_{start}^{end} (UCS) d\ ft ,$$

(4) Determine the required hole size, (5) Find the bit candidates that match the closest unconfined compressive strength of the rock to drill, (6) Determine the end depth of the bit by comparing the historical drilling energy with the cumulative rock strength curve for all bit candidates, (7) Calculate the cost per foot for each bit candidate taking into accounts the rig rate, trip speed and drilling rate of penetration by using the following equation:

$$TOT\ Cost = (RIG\ RATE + SPREAD\ RATE)(T\_TripIn + \frac{footage}{ROP} + T\_Trip) + Bit\ Cost$$

(8) Evaluate which bit candidate is most economic, (9) Calculate the remaining cumulative rock strength to casing point, (10) Repeat step 5 to 9 until the end of the hole section, (11) Build cumulative UCS, (12) Select bits – display bit performance and operating parameters, (13) Remove sub-optimum bits, and (14) Find the most economic bit based on cost per foot.

[00134] The following discussion set forth in the following paragraphs will describe how the 'Automatic Well Planning Bit Selection software' of the present invention will generate a 'Selected Sequence of Drill Bits' in response to 'Input Data'.

[00135] The 'Input Data' is loaded, the 'Input Data' including the 'trajectory' data and Earth formation property data. The main characteristic of the Earth formation property data, which was loaded as input data, is the rock strength. The 'Automatic Well Planning

Bit Selection' software of the present invention has calculated the casing points, and the number of 'hole sizes' is also known. The casing sizes are known and, therefore, the wellbore sizes are also known. The number of 'hole sections' are known, and the size of the 'hole sections' are also known. The drilling fluids are also known. The most important part of the 'input data' is the 'hole section length', the 'hole section size', and the 'rock hardness' (also known as the 'Unconfined Compressive Strength' or 'UCS') associated with the rock that exists in the hole sections. In addition, the 'input data' includes 'historical bit performance data'. The 'Bit Assessment Catalogs' include: bit sizes, bit-types, and the relative performance of the bit types. The 'historical bit performance data' includes the footage that the bit drills associated with each bit-type. The 'Automatic Well Planning Bit Selection software' in accordance with the present invention starts by determining the average rock hardness that the bit-type can drill. The bit-types have been classified in the 'International Association for Drilling Contractors (IADC)' bit classification. Therefore, there exists a 'classification' for each 'bit-type'. In accordance with one aspect of the present invention, we assign an 'average UCS' (that is, an 'average rock strength') to the bit-type. In addition, we assign a minimum and a maximum rock strength to each of the bit-types. Therefore, each 'bit type' has been assigned the following information: (1) the 'softest rock that each bit type can drill', (2) the 'hardest rock that each bit type can drill', and (3) the 'average or the optimum hardness that each bit type can drill'. All 'bit sizes' associated with the 'bit types' are examined for the wellbore 'hole section' that will be drilled (electronically) when the 'Automatic Well Planning Bit Selection software' of the present invention is executed. Some 'particular bit types', from the Bit Selection Catalog, will filtered-out because those 'particular bit types' do not have the appropriate size for use in connection with the hole section that we are going to drill (electronically). As a result, a 'list of bit candidates' is generated. When the drilling of the rock (electronically – in the software) begins, for each foot of the rock, a 'rock strength' is defined, where the 'rock strength' has units of 'pressure' in 'psi'. For each foot of rock that we (electronically) drill, the 'Automatic Well Planning Bit Selection software' of the present invention will perform a

mathematical integration to determine the 'cumulative rock strength' by using the following equation:

$$CumUCS = \int_{start}^{end} (UCS) d\ ft$$

where:

'CumUCS' is the 'cumulative rock strength', and

'UCS' (Unconfined Compressive Strength') is the 'average rock strength' per 'bit candidate', and

'd' is the drilling distance using that 'bit candidate'.

[00136] Thus, if the 'average rock strength/foot' is 1000 psi/foot, and we drill 10 feet of rock, then, the 'cumulative rock strength' is (1000 psi/foot)(10 feet) = 10000 psi 'cumulative rock strength'. If the next 10 feet of rock has an 'average rock strength/foot' of 2000 psi/foot, that next 10 feet will take (2000 psi/foot)(10 feet) = 20000 psi 'cumulative rock strength'; then, when we add the 10000 psi 'cumulative rock strength' that we already drilled, the resultant 'cumulative rock strength' for the 20 feet equals 30000 psi. Drilling (electronically – in the software) continues. At this point, compare the 30000 psi 'cumulative rock strength' for the 20 feet of drilling with the 'statistical performance of the bit'. For example, if, for a 'particular bit', the 'statistical performance of the bit' indicates that, statistically, 'particular bit' can drill fifty (50) feet in a 'particular rock', where the 'particular rock' has 'rock strength' of 1000 psi/foot. In that case, the 'particular bit' has a 'statistical amount of energy that the particular bit is capable of drilling' which equals (50 feet)(1000 psi/foot) = 50000 psi. Compare the previously calculated 'cumulative rock strength' of 30000 psi with the aforementioned 'statistical amount of energy that the particular bit is capable of drilling' of 50000 psi. Even though 'actual energy' (the 30000 psi) was used to drill the first 20 feet of the rock, there still exists a 'residual energy' in the 'particular bit' (the 'residual energy' being the difference between 50000 psi and 30000 psi). As a result, from 20 feet to 30 feet, we use the 'particular bit' to drill once again (electronically – in the software) an additional 10

feet. Assume the 'rock strength' is 2000 psi. Determine the 'cumulative rock strength' by multiplying (2000 psi/foot)(10 additional feet) = 20000 psi. Therefore, the 'cumulative rock strength' for the additional 10 feet is 20000 psi. Add the 20000 psi 'cumulative rock strength' (for the additional 10 feet) to the previously calculated 30000 psi 'cumulative rock strength' (for the first 20 feet) that we already drilled. The result will yield a 'resultant cumulative rock strength' of 50000 psi' associated with 30 feet of drilling. Compare the aforementioned 'resultant cumulative rock strength' of 50000 psi with the 'statistical amount of energy that the particular bit is capable of drilling' of 50000 psi. As a result, there is only one conclusion: the bit life of the 'particular bit' ends and terminates at 50000 psi; and, in addition, the 'particular bit' can drill up to 30 feet. If the aforementioned 'particular bit' is 'bit candidate A', there is only one conclusion: 'bit candidate A' can drill 30 feet of rock. We now go to the next 'bit candidate' for the same size category and repeat the same process. We continue to drill (electronically – in the software) from point A to point B in the rock, and integrate the energy as previously described (as 'footage' in units of 'psi') until the life of the bit has terminated. The above mentioned process is repeated for each 'bit candidate' in the aforementioned 'list of bit candidates'. We now have the 'footage' computed (in units of psi) for each 'bit candidate' on the 'list of bit candidates'. The next step involves selecting which bit (among the 'list of bit candidates') is the 'optimum bit candidate'. One would think that the 'optimum bit candidate' would be the one with the maximum footage. However, how fast the bit drills (i.e., the Rate of Penetration or ROP) is also a factor. Therefore, a cost computation or economic analysis must be performed. In that economic analysis, when drilling, a rig is used, and, as a result, rig time is consumed which has a cost associated therewith, and a bit is also consumed which also has a certain cost associated therewith. If we (electronically) drill from point A to point B, it is necessary to first run into the hole where point A starts, and this consumes 'tripping time'. Then, drilling time is consumed. When (electronic) drilling is done, pull the bit out of the hole from point B to the surface, and additional rig time is also consumed. Thus, a 'total time in drilling' can be computed from point A to point B, that 'total time in drilling' being converted into 'dollars'. To those 'dollars', the bit cost is added. This calculation will yield: a 'total cost

to drill that certain footage (from point A to B)'. The 'total cost to drill that certain footage (from point A to B)' is normalized by converting the 'total cost to drill that certain footage (from point A to B)' to a number which represents 'what it costs to drill one foot'. This operation is performed for each bit candidate. At this point, the following evaluation is performed: 'which bit candidate drills the cheapest per foot'. Of all the 'bit candidates' on the 'list of bit candidates', we select the 'most economic bit candidate'. Although we computed the cost to drill from point A to point B, it is now necessary to consider drilling to point C or point D in the hole. In that case, the Automatic Well Planning Bit Selection software will conduct the same steps as previously described by evaluating which bit candidate is the most suitable in terms of energy potential to drill that hole section; and, in addition, the software will perform an economic evaluation to determine which bit candidate is the cheapest. As a result, when (electronically) drilling from point A to point B to point C, the 'Automatic Well Planning Bit Selection software' of the present invention will perform the following functions: (1) determine if 'one or two or more bits' are necessary to satisfy the requirements to drill each hole section, and, responsive thereto, (2) select the 'optimum bit candidates' associated with the 'one or two or more bits' for each hole section.

[00137] In connection with the Bit Selection Catalogs 52, the Catalogs 52 include a 'list of bit candidates'. The 'Automatic Well Planning Bit Selection software' of the present invention will disregard certain bit candidates based on: the classification of each bit candidate and the minimum and maximum rock strength that the bit candidate can handle. In addition, the software will disregard the bit candidates which are not serving our purpose in terms of (electronically) drill from point A to point B. If rocks are encountered which have a UCS which exceeds the UCS rating for that 'particular bit candidate', that 'particular bit candidate' will not qualify. In addition, if the rock strength is considerably less than the minimum rock strength for that 'particular bit candidate', disregard that 'particular bit candidate'.

[00138] In connection with the Input Data 44a, the Input Data 44a includes the following data: which hole section to drill, where the hole starts and where it stops, the length of the entire hole, the size of the hole in order to determine the correct size of the bit, and the rock strength (UCS) for each foot of the hole section. In addition, for each foot of rock being drilled, the following data is known: the rock strength (UCS), the trip speed, the footage that a bit drills, the minimum and maximum UCS for which that the bit is designed, the Rate of Penetration (ROP), and the drilling performance. When selecting the bit candidates, the 'historical performance' of the 'bit candidate' in terms of Rate of Penetration (ROP) is known. The drilling parameters are known, such as the 'weight on bit' or WOB, and the Revolutions per Minute (RPM) to turn the bit is also known.

[00139] In connection with the Bit Selection Output Data 42b1, since each bit drills a hole section, the output data includes a start point and an end point in the hole section for each bit. The difference between the start point and the end point is the 'distance that the bit will drill'. Therefore, the output data further includes the 'distance that the drill bit will drill'. In addition, the output data includes: the 'performance of the bit in terms of Rate of Penetration (ROP)' and the 'bit cost'.

[00140] In summary, the Automatic Well Planning Bit Selection software 42c1 will: (1) suggest the right type of bit for the right formation, (2) determine longevity for each bit, (3) determine how far can that bit drill, and (3) determine and generate 'bit performance' data based on historical data for each bit.

[00141] Referring to figure 15, the 'Automatic Well Planning Bit Selection Software' 42c1 of the present invention will generate the display illustrated in figure 15, the display of figure 15 illustrating 'Bit Selection Output Data 42b1' representing the selected sequence of drill bits which are selected by the 'Automatic Well Planning Bit Selection Software' 42c1 in accordance with the present invention.

[00142] Refer now to figures 16.

[00143] A functional specification associated with the 'Automatic Well Planning Bit Selection Software' 42c1 of the present invention will be set forth in the following paragraphs with reference to figures 16.

Select Drilling Bits

Characteristic Information

Goal In Context:	This use case describes the process to select drilling bits Right Click the Mouse to 'accept changes'.
Scope:	Select Drilling Bits
Level:	Task
Pre-Condition:	The user has completed prior use cases and has data for lithology, UCS, and BitTRAK bit catalog.
Success End Condition:	The system confirms to the user that IADC Code per section, estimated ROP and drilling section has been determined including the operating parameter ranges WOB, RPM.
Failed End Condition:	The system indicates to the user that the selection has failed.
Primary Actor:	The User
Trigger Event:	The user completed the cementing program

Main Success Scenario

Step	Actor Action	System Response
1	The user accepts the mud design.	The system uses the algorithm listed below to split the hole sections into bit runs and selects the drilling bits for each section based on rock properties, forecasted ROP and bit life and economics. The system displays in a grid: Bit size, IADC code, bit section end depth, footage, ROP, WOB, RPM, WOB, Total revolutions, Cumulative excess ratio, bit cost. The system displays in 3 different graphs: <u>Graph 1:</u> MD, UCS, Bit Average UCS, casing point and interactively the bit section end depth. <u>Graph 2:</u>

ROP, RPM, WOB (all interactive) and bit size
Graph 3:
Hours on bottom vs measured depth, horizontal lines for bit section end depth and casing points. All non-interactive.
The system displays the UCS, the bit sections with IADC codes, the proposed RPM & WOB, and the anticipated ROP for each bit.

Scenario Extensions

Step	Condition	Action Description

Scenario Variations

Step	Variable	Possible Variations
1	Conductor pipe is not drilled but jetted or driven.	No bits for this section.
2	The user may modify before accepting: bit selection (IADC), ROP, bit-section length (=footage), or drilling parameters (WOB,RPM,ROP)	The system updates the bit selections. The system confirms to the user the selection has been saved successfully. The use case ends successfully.

Related Information

Schedule:	Version 1.1
Priority:	Must
Performance Target:	N/A
Frequency:	N/A
Super Use Case:	Swordfish Use Case IPM III – Design the Well Candidate
Sub Use Case(s):	N/A
Channel To Primary Actor:	N/A
Secondary Actor(s):	N/A
Channel(s) To Secondary Actor(s):	N/A

Business Rules

BIT 1 Cumulative number of revolutions for a roller cone bit for risk estimation.

Rule	
Short Description	Cumulative number of revolutions for a roller cone
Description	The risk of seal failure of a roller cone bit is increasing with increasing number of revolutions of the (sealed journal) roller cone bearing. In real life, the bearing can not exceed 750,000 revolutions. The total number of revolutions is used for risk calculations,
Formula	1.1.1.1.Total revolutions=RPM*60*Hrs<750,000 revolutions
Score	Calculate and display for each selected bit the number of revolutions. Risk is low for less than 600,000 revolutions Risk is medium for 600,000 – 700,000 revs Risk is high for more than 700,000 revs.

BIT 2 Minimum Total Flow area

Rule	
Short Description	Minimum nozzle size and Total Flow area
Description	The minimum nozzle size is 3 x 10/32 inch nozzles. Consequently the minimum Total Flow area is 0.23 sqinch
Formula	
Score	

BIT 3 Extent bit section length in case casing point is within 125%

Rule	
Short Description	Extent bit section length in case casing point is within 125%
Description	In order to prevent a short bit run to reach the casing point, the system should suggest to extent the proposed bit section length. The amount to extent should be limited to 1.25 times the originally proposed footage. Consequently, the risk is increased.
Formula	
Score	

1. Tripping for bit…economics of pulling a bit versus continuing to drill….version 1.5

BIT 4 Hole sizes for bicenter and ream-while-drilling tools.

Rule	
Short Description	Hole sizes for bicenter and ream-while-drilling tools.
Description	Bicenters and reamers can be used to drill a larger hole than the drift diameter of the previous casing. The "pass through" diameter needs to be smaller than the drift of the previous casing. ROP data should be based on hole diameter instead of pass through diameter.
	Pass Through / Hole Diameter: 17 1/2 — 22 14 3/4 — 17 1/2 12 1/4 — 14 3/4 10 5/8 — 12 1/4 8 1/2 — 9 7/8 6 — 7 1/4 4 1/4 — 6 1/4
Formula	
Score	

Note that the pass through diameter corresponds with the nominal size of common drill bits.

The following information is optional, and is used only to populate WOB and RPM data in the Catalog:

WOB = -6.6067(UCS)^2 + 1231.9(UCS) + 5000
RPM = 0.0148(UCS)^2 - 2.997(UCS) + 200
(for bits larger than 8 1/2")

WOB = -1.8375UCS^2 + 424.81UCS + 2000
RPM = 0.0148UCS^2 - 2.997UCS+ 200
(for bits smaller than 8 1/2")

Build in logic if UCS exceeds 100 kpsi than drilling parameters remain constant.

Common bit sizes

Inch	Inch	Inch	Inch
4 1/2	7 5/8	11	20
4 5/8	7 7/8	12	22
4 3/4	8 3/8	12 1/4	24
5 5/8	8 5/8	13 1/4	26
5 7/8	8 3/4	14 1/2	36
6	9	14 3/4	
6 1/8	9 1/2	15	
6 1/4	9 5/8	16	
6 1/2	9 7/8	17 1/2	
6 3/4	10 5/8	18 1/2	

<u>Mining the BitTRAK database:</u>

- Bits larger than 4 ½"
- Only new bit, disregard the rerun bits (RR's)

The following are optional, used only to populate data in the Catalog:

- Use only the records with a non-empty data field for the 1) IADC code 2) WOB Max, and 3) RPM Max
- Only bit sizes with more than 50 records
- Only records since January 1999. (note that the spud date has a lot of blank fields)
- "Depth in" is positive number. If Depth In is negative, disregard the record
- Footage is larger than 25 ft
- Only hours larger than 10
- Use "WOB Max" and "RPM Max" to calculate the average drilling parameters.
- Ensure that the following rounding errors are not occurring. Obviously the records should be merged. The bit size should be expressible as a fraction. Enforce the closest fraction to the bit size.

  4.75558 instead of 4 ¾

  6.00456 instead of 6"

  6.13064 instead of 6.125 (6 1/8")

  6.25672 instead of 6 ¼"

  7.88 instead of 7.875 (or 7 7/8")

8.50646 instead of 8 ½"

8.75862 instead of 8 ¾"

etc

[1] Drill bit selection

Assumptions:

The following assumptions limits the number of bits in the BitTRAK catalog.

- No air cooled bearings.
- No roller bearing with gage protection: upgrade to the sealed roller bearing with gage protection.
- Only sealed friction bearings with gage protection instead of the sealed friction bearings without gage protection.

Files to use

The following files can be used to build the bit selector

1. "roller cone table vx"
2. "UCS to IADC"
3. "UCS data from earth model"

1.2. Selection method

1. Select in the bit table the correct bit size.

For example a 12 ¼" bit (see Table 7 12 ¼" bits roller cone bits.).

2. Select the bit with the minimum KPSIFT for that bit size

For example: a IACD111 bit with 2134 KPSIFT with a footage of 1067 ft see Table 7 12 ¼" bits roller cone bits.

3. Compute from the UCS log:
   a. The cumulative KPSIFT (calculated by the sum of the multiplication of the UCS (in KPSI) and the depth interval (in feet)

b. Determine the footage while the value of the cumulative KPSIFT is not exceeding the KPSIFT from the bit table.

c. Determine that the UCS-footage corresponding to the cumulative KPSIFT is not exceeding the hole section footage

In the example:

Footage	KPSIFT	Excess	Cum KPSIFT
650	39.72458	39.72458	1996.902
659	42.35698	42.35698	2039.259
669	14.2982	0	2053.557
679	14.26794	0	2067.825
689	115.5774	115.5774	2183.402
699	86.10659	86.10659	2269.509
709	125.4547	125.4547	2394.964

Table 1 UCS data related to IACD111 bit.

The cumulative KPSIFT of 2067 is the closest fit to the 2134 KPSIFT for the bit. The corresponding calculated footage is 679 ft, less than the bit footage of 1067 ft.

d. If the bit footage exceeds the footage with equal KPSIFT, a bit with higher KPSIFT need to be selected. (or, alternatively a bit with a higher IADC classification. This needs to be investigated and addressed below.) As long as the footage is not exceeding the hole section repeat the described sequence with a second bit.

e. Ensure when selecting the IADC code for a bit, that it meets the following two criteria:

   1. The bit is not encountering formations exceeding the maximum UCS for more than 20 ft

   2. The bit is not encountering formations with a UCS lower than the specified minimum over a interval exceeding 50 ft.

In case the bit footage is less than the calculated footage from the UCS data, a bit with higher KPSIFT needs to be selected. In the example, the next 12 ¼" bit is an IACD115 with 2732 KPSIFT with a footage of 1366 ft.

Footage	KPSIFT	Excess	Cum KPSIFT
768	14.93143	0	2584.996
778	45.01108	45.01108	2630.007

787	45.52515	45.52515	2675.532
797	14.82596	0	2690.358
807	65.05947	65.05947	2755.418
817	14.26794	0	2769.686
827	220.1043	220.1043	2989.79
837	104.2346	104.2346	3094.025
846	38.57671	38.57671	3132.601
856	184.551	184.551	3317.152
866	14.26794	0	3331.42

Table 2 UCS data related to IADC115 and IADC117

The second bit corresponds with a cumulative KPSIFT of 2690, with 797 ft footage. This is still less than the average 1366 ft for this bit type. The third bit from the catalog is an IADC117 with 2904 KPSIFT and 1452 ft footage. This corresponds with 2770 KPSFT and 817 ft, which is still less than the bit's footage. The forth bit has a cumulative KPSIFT of 8528 and 1066 for footage. Now, the footage of 1752 (with corresponding 8525 KPSIFT) exceeds the bit's footage.

Footage	KPSIFT	Excess	Cum KPSIFT
1713	114.8937	114.8937	8245.098
1722	72.11995	72.11995	8317.218
1732	76.65248	76.65248	8393.87
1742	57.09546	57.09546	8450.966
1752	74.17749	74.17749	8525.143
1762	61.46744	61.46744	8586.611
1772	66.07676	66.07676	8652.687
1781	79.78368	79.78368	8732.471

Table 3 UCS data related to IADC417 bit

Footage	KPSIFT	Excess	Cum KPSIFT
2707	78.74228	78.74228	14675.89
2717	62.11594	62.11594	14738.01
2726	72.90075	72.90075	14810.91
2736	158.7009	158.7009	14969.61
2746	117.0117	117.0117	15086.62
2756	96.08162	96.08162	15182.7
2766	20.21608	0	15202.92

Table 4 UCS data related to IADC137 bit

4. Compute the excess UCS over the bit's threshold. The bit selection is reduced to two candidates, each with a maximum UCS. In case the actual UCS per foot exceeds the maximum UCS of the particular bit, the summation of the difference is calculated. Negative difference between the actual UCS and bit's UCS is set to zero. The bit with the smallest cumulative excess over its threshold is selected for drilling the section.

In the example: The second criterion is used to make a choice between the third (IADC 117) and the forth bit (IADC417). The threshold for the IADC117 is 2 KPSI, and the calculated cumulative excess pressure is 159 KPSI. The threshold for the IADC417 is 8 KPSI, and the calculated cumulative excess pressure is 125 KPSI. Therefore the IADC417 is selected. Note that in case the IADC137 (one category more aggressive than the IADC117) was selected, the resulting footage would have been 2736 ft with an excess of 354 KPSI. In case of the next IADC code, the more aggressive bit.

Min UCS	Max UCS	Avg UCS	IADC 1	IADC 2	IADC 3	More than 50 ft under minimum, or more than 20 ft over the maximum
0	25	2	117	111	115	(111 for top hole. 117 is most common for 17 1/2" and smaller)
0	25	4	127	121		(121 only in 22" size. 127 is 5 times more common, especially in smaller sizes)
0	25	6	131	135	137	(not available in every size)
0	30	8	417			(415 is not that common, only in 17.5)
0	35	10	427			
0	40	12	437	435		(437 is 8 times more common)
0	40	14	447	445		(447 is 5 times more common than 445)
5	50	16	517	515		(517 is 74 times more common than 515)
5	50	18	527			
5	50	20	537	535		(537 is 177 times more common than 535)
5	50	22	547			
10	60	24	617			
10	60	26	627			
10	60	28	637			
60	60	30	647			
15	70	33	717			
15	70	36	737			

15	70	40	747			
15	100	50	817			
20	100	60	837			If formation contains > 20 ft of chert, or pyrite, or quartzite

Table 5 Relation between the IADC code and the formation UCS including lower and upper limits

5. Select the next bit to drill the remainder of the hole section. In order to select the next bit, the Cumulative K

1.2.1. Algorithm refinements:

If the hole size is not present in the BitTRAK table then select the following bit size:

- Select the bit size that is closest to the required hole size
- With two candidates that are equally close to the required hole size, select the smallest bit size from the BitTRAK table

If there is only one bit in the BitTRAK table for the required size that the algorithm has to select the bit (and use the calculated earth model KPSIFT)

1.2.2. Risk assessment

Risk related to formation hardness is:

- Low for Excess KPSIFT < 10% of cumulative KPSIFT
- Med for Excess KPSIFT > 10% and < 20% of cumulative KPSIFT
- High for Excess KPSIFT >10% of cumulative KPSIFT

Risk related to bit footage is:

- Low for UCS cumulative footage < 1.2 x bit table footage
- Med for UCS cumulative footage < 1.5 x bit table footage
- High for UCS cumulative footage < 2 x bit table footage

Summary table

The '417 IADC code' bit set forth in the table below has the lowest excess KPSI and therefore the lowest risk. Swordfish should suggest the IADC417 bit. The method is to

follow the sequence of bits with an increasing KPSIFT and not necessarily increasing IADC code.

	Bit table		UCS data		
IADC code	Bit KPSIFT	Bit Footage	Cum KPSIFT	Cum Footage	Excess KPSI
111	2134	1067	2067	679	N/A
115	2732	1366	2690	797	N/A
117	2904	1452	2770	817	159
137	14952	2726	14810	2726	354
417	8528	1066	8525	1752	125

Table 6 Summary table of bit selection

BIT_SIZE	IADC_	# Recon	Depth in	Depth Out	Footage	STDDEV Footage	Hours	ROP	Max UCS	KPSIFT
12.25	111	414	2602	1870	1067	26.21	20.99	34.6	2	2134
12.25	115	172	5640	1827	1366	41.75	27.51	40.9	2	2732
12.25	117	1384	5731	2084	1452	48.29	36.85	38.5	2	2904
12.25	417	169	4252	1411	1066	41.47	26.42	32.8	8	8528
12.25	435	99	6638	1136	988	51.58	31.01	26.1	12	11856
12.25	515	53	6018	878	778	41.78	25.84	35.8	16	12448
12.25	427	63	7904	1776	1271	59.06	27.83	27.8	10	12710
12.25	137	88	5645	2432	2492	52.24	38.93	44.7	6	14952
12.25	437	992	7160	1638	1466	59.06	37.86	28	12	17592
12.25	445	132	6664	1598	1370	54.38	36.95	31.8	14	19180
12.25	517	1550	3521	6872	1340	1214	67.44	24.1	16	21440
12.25	547	658	5191	2280	1152	102.82	51.3	13.7	22	25344
12.25	737	54	7465	1869	926	100.03	46.59	15.9	36	33336
12.25	537	1212	3764	6437	1740	1360	77.58	26	20	34800
12.25	527	930	530	4936	2182	1307	98.5	26	18	39276
12.25	647	97	9684	923	1358	55.23	39.09	22.3	30	40740
12.25	617	449	7980	7181	1747	1460	86.11	22.3	24	41928
12.25	627	574	445	8202	1627	950	99.81	17.4	26	42302
12.25	447	548	7904	1377	3499	57.91	30.4	76.1	14	48986
12.25	637	96	7644	1923	2238	77.66	61.87	26.7	28	62664

Table 7 12 ¼” bits roller cone bits.

1.2.3. RPM for PDM’s.

In case a PDM is selected in the BHA design, the RPM differs from the lookup table. For the selected PDM (size and type), the RPM is calculated:

$$RPM = 60 + Qtest(\mathrm{Re}v / Gal)$$

Size	OD	Lobes	Stages	dPtest	Qtest	MW	dP w/H2O	Min flow	Max flow	Rev/gal
A287	2.875	5/6	3.3	140	80	8.34	190	20	130	6
	2.875	5/6	7.0	194	80	8.34	244	20	130	5.8
	2.875	7/8	3.2	191	90	8.34	241	30	130	4.2

A350	3.5	4/5	5.0	138	100	8.34	188	30	160	3.3
	3.5	7/8	3.0	168	110	8.34	218	30	160	1.6
A475	4.75	4/5	3.5	115	250	8.34	165	100	350	1.1
	4.75	4/5	6.0	151	250	8.34	201	100	350	1.1
	4.75	7/8	2.2	170	250	8.34	220	100	350	0.6
A675	6.75	4/5	4.8	152	600	8.34	202	300	700	0.5
	6.75	4/5	7.0	184	600	8.34	234	300	700	0.5
	6.75	7/8	3.0	181	600	8.34	231	300	700	0.3
	6.75	7/8	5.0	210	600	8.34	260	300	700	0.3
A800	8	4/5	3.6	151	900	8.34	201	300	1100	0.3
	8	4/5	5.3	175	900	8.34	225	300	1100	0.3
	8	7/8	3.0	218	900	8.34	268	300	1100	0.2
	8	7/8	4.0	233	900	8.34	283	300	1100	0.2
A962	9.625	3/4	4.5	300	900	8.34	350	600	1500	0.2
	9.625	3/4	6.0	570	900	8.34	620	600	1500	0.2
	9.625	5/6	3.0	280	900	8.34	330	600	1500	0.1
	9.625	5/6	4.0	305	900	8.34	355	600	1500	0.1
A1125	11.25	3/4	3.6	395	1250	8.34	445	1000	1700	0.1

PDC bit selection

1. Characteristic Information

The following defines information that pertains to this particular use case. Each piece of information is important in understanding the purpose behind the Use Case.

Goal In Context:	This use case describes the selection of PDC bits
Scope:	
Level:	Task
Pre-Condition:	The user has completed prior use cases and has data for mudline, total depth, UCS, and bit catalogs.
Success End Condition:	The system confirms to the user that IADC Code per section, estimated ROP and drilling section has been determined including the operating parameter ranges WOB, RPM.
Failed End Condition:	The system indicates to the user that the selection has failed.
Primary Actor:	The User
Trigger Event:	The user accepts the drill fluid selection

Main Success Scenario

This Scenario describes the steps that are taken from trigger event to goal completion when everything works without failure. It also describes any required cleanup that is done after the goal has been reached. The steps are listed below:

Step	Actor Action	System Response
1	The user accepts the last end condition	The system uses the algorithm described below to split the hole sections into bit runs and selects the appropriate drilling bits (including PDC bits) for each section based on rock properties, forecasts ROP and predicts bit life. The system displays the results similar to the results currently displayed for the roller cone bits.

Scenario Extensions

This is a listing of how each step in the Main Success Scenario can be extended. Another way to think of this is how can things go wrong. The extensions are followed until either the Main Success Scenario is rejoined or the Failed End Condition is met. The Step refers to the Failed Step in the Main Success Scenario and has a letter associated with it. I.E if Step 3 fails the Extension Step is 3a.

Step	Condition	Action Description
2a		
3a		

Scenario Variations

If a variation can occur in how a step is performed it will be listed here.

Step	Variable	Possible Variations
	User modifies drilling performance	System updates the drilling performance

Related Information

The following table gives the information that is related to the Use Case.

Schedule:	Version 2004.1
Priority:	Must
Performance Target:	N/A
Frequency:	Every time a new scenario is started.
Super Use Case:	Swordfish Use Case IPM I – Generate Well Inputs
Sub Use Case(s):	Roller cone bit selection
Channel To Primary Actor:	N/A
Secondary Actor(s):	N/A
Channel(s) To Secondary Actor(s):	N/A

2. Assumptions and limitations

- Only PDC fixed cutter bits, no impregnated bits
- The algorithm does not select between matrix or steel body PDC bits. However, the algorithm should be able to handle either one
- The PDC cutter size is assumed to be an indicator for the formation hardness. The reasoning is that most bits have a combination of cutter sizes and that a relative larger number of small cutters equips the bit to drill harder formations.

3. IADC Classification

The IADC classification consists of four characters, A, B, C and D.

A	*B*	*C*	*D*
Bit body	*Formation type*	*Cutting structure*	*Bit profile.*

"M"	Matrix
"S"	Steel
"D"	Diamond

Example	
M	Matrix
4	Medium
3	PDC 13mm
4	Long profile

1	Very soft	2	PDC, 19mm
		3	PDC, 13mm
		4	PDC, 8mm
2	Soft	2	PDC, 19mm
		3	PDC, 13mm
		4	PDC, 8mm
3	Soft to medium	2	PDC, 19mm
		3	PDC, 13mm
		4	PDC, 8mm
4	Medium	2	PDC, 19mm
		3	PDC, 13mm
		4	PDC, 8mm

1	Short fishtail
2	Short profile
3	Medium profile
4	Long profile

The first character (A) is either M for Matrix body or S for Steel body PDC bits The second numeric (B) indicates the formation hardness, while the third numeric character (C) describes the cutter size. Both characters B and C are used in the algorithm for the formation hardness. The forth character (D) describes the bit profile ranging from short to long profile.

4. Algorithm

Similar to the roller cone bit selection, there is a relation assumed between the IADC classification for PDC bits and the Unconfined Compressive rock strength. In the interval the PDC bit should not drill formations with a UCS below the minimum UCS or above the Maximum UCS. The average UCS is used to find the optimum bit candidate.

IADC	IADC	MIN UCS	AVG UCS	MAX UCS
M12	12	0	1.00	4
M13	13	0	2.73	5
M14	14	1	4.45	7
M22	22	2	6.18	9
M23	23	3	7.91	12
M24	24	3	9.64	13
M32	32	4	11.36	14

M33	33	4	13.09	16
M34	34	5	14.82	19
M42	42	5	16.55	20
M43	43	6	18.27	22
M44	44	7	20.00	24

Refer now to figure 16.

Bit Profile Selection

The bit profile (Character D) is selected by computing the Directional Drilling Index (DDI). The algorithms to calculate the DDI is already implemented in the risk assessment task and is described below to be complete.

For each PDC bit candidate (selected based on the UCS criteria) the DDI is calculated. The maximum value of the DDI is used to filter out the PDC bits that do not qualify based on bit profile.

DDI from	DDI to	Bit Profile	Profile description
- Infinity	4	4	Long
4	5	3	Medium
5	6	2	Short
6	100	1	Short fishtail

Tentative classification values for the bit profile

5. Bit Economics

For each bit candidate the economics are calculated, taking into account the drilling performance and the tripping cost. This is similar to the selection method for roller cone bits.

6. Appendix

7. Preliminary PDC bit catalog

Below is a copy of the preliminary PDC bit catalog. The rollercone and PDC bits are listed in two separate bit catalogs.

BIT_SIZE	BIT_TYPE	IADC	FOOTAGE	HOURS	ROP	AVG RPM	AVG WOB	KREV	MIN UCS	AVG UCS	MAX UCS	KPSIFT	BitCost
8.5	BD445	M443	1305.0	21.6	60.4	100.0	12.5	129600	7	20.0	24	26100	35000
8.5	DS110	M323	2463.9	72.0	34.2	120.0	25.0	518400	4	11.4	14	27999	41040
8.5	DS56	M432	1625.0	44.1	68.5	110.8	19.6	293022	6	18.3	22	29692	25864
8.5	FM2546	M433	2076.0	68.5	30.3	80.0	10.0	328800	6	18.3	22	37934	25000
8.5	G445	M332	2290.0	14.0	163.6	80.0	10.0	67200	4	13.1	16	29979	35000
8.5	G447	M432	492.1	44.2	14.2	121.0	18.5	320455	6	18.3	22	8993	30429
8.5	K33	M432	179.0	38.6	4.6	120.0	27.0	761497	6	18.3	22	3271	36957
8.5	K33B	M432	161.0	35.0	4.6	167.5	34.0	351750	6	18.3	22	2942	26000
9.875	DS56	M432	2092.0	83.7	25.0	104.4	13.2	524352	6	18.3	22	38226	35000
9.875	DS59	M432	1515.1	60.6	25.0	110.0	11.4	400117	6	18.3	22	27685	35000
9.875	DS70	M432	2367.9	94.7	25.0	116.2	10.2	660307	6	18.3	22	43268	35000
9.875	G447	M432	1798.0	71.9	25.0	89.6	11.8	386590	6	18.3	22	32855	35000
9.875	LP661	M432	2088.0	83.5	25.0	130.0	25.0	651456	6	18.3	22	38153	35000

<u>Directional Drillability Index (per depth)</u>

Short Name: DDI

Category: Stuck, Mechanical

Calculation: Calculate the DDI using the "Resample data"

Note: The DDI is calculated for the entire well. Therefore, the DDI is not displayed as a risk track, but displayed in the risk summary overview.

$$DDI = LOG_{10}\left[\frac{MDxAHDxTORTUOSITY}{TVD}\right]$$

MD, TVD in meters (or feet???)

Tortuosity : $TOR = \sum_i DLS_i$

AHD = Along hole displacement. In Swordfish, the AHD will be calculated using the Pythagorean principle (using the resample data)

$$AHD = \sum_{n=i}\left[\sqrt{(X_{n+1} - X_n)^2 + (Y_{n+1} - Y_n)^2}\right]$$

- High: DDI > 6.8
- Medium DDI < 6.8 and > 6
- Low: DDI < 6

8. Alternative classification for the bit profile selection

This selection method is based on using simply the dogleg severity to determine the bit profile.

DLS from	DLS to	Bit Profile
0	0.5	4
0	1	3
0.5	2	2
1	10	1

[00144] The invention being thus described, it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.